CALIFORNIA SEWAGE WORKS JOURNAL

Official Publication of the California Sewage Works Association

Vol. XIII :: 1941 :: No. 2

Minutes of Thirteenth Annual Spring Conference
At Santa Cruz, California, April 20, 21, 22, 1941

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Operating Problems

81

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Cross Connections

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Hydrogen Sulphide
Corrosion Control

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Cooling of Gas Engines

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Mechanics of Flocculation

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Military and Defense Problems

Acknowledgment

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CALIFORNIA SEWAGE WORKS JOURNAL

Address all Communications to President, California Sewage Works Association, 2540 Benvenue Avenue, Berkeley, California

This Journal, together with the Journal of the Federation of Sewage Works Association, free to members. . . . Extra copies, $1.00.

Published by

WESTERN CITY

458 South Spring Street, Los Angeles, California

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Affiliated with the National Federation of Sewage Works Associations

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California Sewage Works Journal

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ANNOUNCEMENT

October 12-14 are the dates which have been set for the 14th Annual Fall Convention of the Association. The meeting place is Sacramento.

The League of California Cities also meets at Sacramento during the same week.

Ted Gregory and his committee are busy lining up one of the best programs we have ever had.

Carl Hoskinson and his committee are already busy taking care of the local arrangements which will make your stay in Sacramento extremely pleasant.

Wayland Jones and his Publicity Committee are organizing a publicity campaign which should not let you forget the meeting place or dates.

Ralph Sotter and his committee are working on a special program for operators which operators and even others cannot afford to miss.

One-half day of the Fall Meeting will be a joint session with the Public Works Officers' Department of the League of California Cities. City engineers will have a particular interest in this portion of the program.

MARK THESE DATES ON YOUR CALENDAR NOW

13TH ANNUAL SPRING CONFERENCE CALIFORNIA SEWAGE WORKS ASSOCIATION

Santa Cruz, California, April 20-22, 1941

MINUTES OF THE MEETING

Sunday, April 20

President Harold Farnsworth Gray assembled many operators and other interested members in the Bay View Room of the Casa Del Rey Hotel at 4:20 P.M., for the purpose of conducting an operator's symposium. Highlights of the symposium were discussions on Digester Troubles, Sewage and Sludge Pumps, Switch Boards, Pump Starters, Float Rods and Floats. Mr. Ralph Sotter presided over this symposium.

At 7:00 P. M. members and guests assembled in the Trocadero Bowl for a buffet supper. Continuing along the line of operation, Mr. T. R. Haseltine presented a very interesting and informative address under the general topic, "Operating Problems in Other Parts of the United States."

Monday, April 21

Harold May, Chairman of the Local Arrangements Committee, assembled the entire group in the lobby of the hotel for the purpose of forming a caravan to sewage treatment plants of interest. The caravan proceeded to the Main Garrison at Fort Ord. The Association was taken on a short tour through the garrison and then to the newly completed installation of Doten septic tanks used for treatment of the garrison sewage.

The next stop was made at Carmel. Bernard Rowntree explained the operation of the various features of the plant.

A stop was made for luncheon at Biff's Place, near Monterey. Past President Pardee, City Manager at Monterey, was called on during the luncheon meeting for a few remarks.

The activated sludge treatment plant at Salinas was next observed. As this plant was out of service for repair purposes, many of the group were given the opportunity of observing the construction details of this type of plant.

The caravan was concluded with a visit to the East Garrison of Fort Ord. The treatment plant here is unique in that all sewage is pumped from the camp to the top of a nearby hill, where Doten type septic tanks and drainage ponds are located.

Members and guests assembled at the Trocadero Bowl Monday evening for the Spring Conference banquet. The Association was honored by the presence of C. A. Emerson, President of the Federation of Sewage Works Associations, as the guest speaker of the evening.

Brief talks of welcome were given the group by Mayor C. D. Hinkle and by County Health Officer John D. Fuller, M. D. President Gray presented Past-Presidents Goudey, Reinke, Haseltine, and Reynolds during the evening.

President Gray gave a fine eulogy of Past-President Alexander Bell, and adjourned the meeting in memory of him.

Tuesday, April 22

President Gray called the business meeting of the Association to order in the Bay View Room at 9:00 A. M. During the meeting, the following reports were presented:

Constitutional Revision Committee—Progress Report, L. B. Reynolds; Publicity Committee, Wayland Jones; Award Committee, Albert Castro; Legislative Committee, Carl Hoskinson; Finance Committee, J. F. Smith; Certification Committee, R. D. Woodward; Design Practice Committee, Richard Pomeroy; Industrial Wastes Committee, W. T. Knowlton; Safety Standards Committee, Joseph Corrao; Program Committee, Ray Goudey; Operators Panel, R. R. Sotter. A report on schools, submitted by Chairman R. L. Derby, was read by the Secretary and supplemented by G. E. Arnold. The business meeting was adjourned at 10:30 A. M.

During the technical session following, the following papers were presented:

Hydrogen Sulphide in Sewage, Fred D. Bowlus; Corrosion of Iron by Sulphides, Richard Pomeroy; Cross Connections in Sewerage, G. E. Arnold.

The following participated in a discussion of the above papers:

Roy Ramseier, Ted Haseltine, Richard Pomeroy, R. F. Goudey, William A. Allen, Harvey Ludwig.

A luncheon meeting was held at the Trocadero Bowl at 12:15 P. M. During this meeting, Ted Haseltine presented a review of the Chemists' Breakfast held that morning. R. D. Woodward of Laguna Beach presented a life-saving device made of rope. He also exhibited some electric wire with a special protective coating which seemed to be quite serviceable around sewage treatment plants. Technical sessions were resumed at 2:00 P. M.

The following papers were presented:

Mechanism of Flocculation in Water and Sewage Practice, H. F. Ludwig and Russell G. Ludwig; Use of Port Orford Cedar at Sewage Treatment Plants, Edgar A. Brown; Cooling of Sewage Gas Engines, J. H. Wallace; Detection of Metallic and War Gas Poisons in Sewage, R. F. Goudey; Sewerage Facilities of Army Contonments, Dwight Bissell, M. D.

Harvey Ludwig, Ted Haseltine, Harold Gray, Edgar Brown, William Allen, John Skinner, John Maga, Harold Davey, J. H. Wallace, J. C. Clark, Roy E. Ramseier, and Dr. Dwight Bissell participated in very interesting discussions concerning the above papers.

The 83 members and 32 guests who attended the Conference adjourned to their various ways at 5:00 P. M.

Respectfully submitted,

William T. Ingram, *Secretary.*

REPORT OF OPERATORS SYMPOSIUM
SANTA CRUZ, CALIFORNIA

The meeting was called to order at 4:20 P. M. in the Bay View Room of the Casa del Rey, with approximately 30 operators present.

Mr. Ralph Sotter opened the meeting and welcomed those present, and asked all present to please present their problems so they could be discussed.

The first discussion on digester trouble which was brought out by Mr. H. W. Davey of Bakersfield Division, followed by R. Sotter on Richmond Sunset digester, W. Jones on Stockton Tank, Walter J. Walkero of Decoto on their Imhoff Tank, Mr. T. R. Hazeltine on some of his experiences, William Ingram on Stockton Tanks, James Parr on Manteca Tanks.

Mr. H. W. Davey then asked about sludge pumps. In this discussion entered the following: Mr. L. E. Stickles, Santa Cruz; William A. Allen, Pasadena; Carl F. Tennant, Long Beach; and Harold K. Palmer, Los Angeles.

The next discussion on Switch Boards and Pump Starters was proposed by Mr. A. B. Shearer of San Anselmo. Mr. Sotter told of the Infra-Red globes placed back of their switch boards to stop condensation. Mr. Charles Baugh, chemist, suggested that a chemical be used for the same purpose.

The next discussion was on Float Rods and Floats. There were a great many suggestions on methods used in the different plants. Mr. Benas told of a new type switch.

Mr. James Parr of Manteca told of the failure of their pipe line.

F. Wayland Jones

CHEMIST'S BREAKFAST

A chemist's breakfast was held at 7 A. M. Tuesday morning in the Trocadero Bowl with nine chemists or "would-be chemists" attending.

Harvey Ludwig called attention to the difficulty of obtaining satisfactory results with the B.O.D. test when analyzing industrial wastes. It was his opinion that the oxygen consumed test gave a better picture of the strength of such wastes. Roy Ramseier and Ray Goudey agreed with that opinion and stated that there was usually good correlation between oxygen consumed and chlorine demand tests on sewage containing industrial wastes while B.O.D.'s were frequently low. Dick Pomeroy agreed but felt that what was really needed was a simple means of determining total organic carbon. He described two "not so simple" procedures for that determination. Paul Shaw stated that in the fish and game laboratory they preferred to use natural river water taken from the stream in question instead of standard diluting water in setting up B.O.D. samples.

Ted Haseltine requested information on methods of determining volatile acids in sludge. Said information was supplied by Chuck Baugh. A general discussion revealed that volatile acid tests and bicarbonate or alkalinity tests were probably the two most important determinations in studying sludge digestion tank performance. Ray Goudy suggested that there might be a correlation between the volatile acid content of a sludge and its drying characteristics.

Pomeroy and Baugh described large sludge drying beds used at the Los

Angeles County plant. These beds have no under-drains and are laid out in natural ground as contour checks having a slope of 2 inches per 100 ft. Sludge is applied continuously at one end for several days. The water separates and flows ahead of the solids, thereby escaping and seeping into the ground.

Ted Haseltine called attention to the fact that although coagulant dosages were usually reported as a percentage of the total solids when sludge was dried on vacuum filters that both that method and a "lb. per unit volume of wet sludge" method were used in reporting coagulants used for bed drying of sludge; one or the other of these methods was illogical in his opinion. Bill Allen stated that although coagulants were reported as a percentage of total solids in vacuum filtration work that the method of reporting was of little importance. In actual operation the proper dosage could only be determined by trial and an experienced operator was of more value than a chemist on the job.

R. D. Woodward described his troubles with moisture collecting in electrical conduits and displayed samples of ordinary insulated wire and "synthole" wire which had been exposed for six months to (a) submergence in sewage and (b) suspension in moist gases above settling sewage. In both cases the "synthole" insulation proved superior. He also described troubles with condensation in boiler flue piping of both galvanized iron and transite.

The meeting adjourned at 9 A. M. with all in favor of repeating the chemists breakfast again at the fall meeting.

REPORT, COMMITTEE ON SAFETY STANDARDS

The Committee on Safety Standards originally consisted of ten members, five in the southern part of the state and five in the northern part. At the suggestion of Mr. F. S. Currie, Chairman, the Committee was split into a northern and southern section, each working separately and yet in conjunction with each other.

The subject of Safety Standards is a broad one, taking in not only questions of operation but of design as well. The letter of assignment did not state specifically the subject matter to be covered, and therefore the northern section has attempted to gather available data on the subject for presentation to the Committee as a whole with the thought that this data might be used as a basis for laying out a long-range program. A portion of this program could be assigned for study and presentation at the Fall Convention.

An attempt has been made by the Committee to list some of the references to safety standards adaptable to sewage treatment plants. In addition, contacts have been made with those in charge of safety in large industrial organizations which would have similar problems. From the foregoing it has been concluded that the subject has two distinct parts: (1) safety standards to be considered in design, and (2) safety rules and regulations pertaining to operation. No attempt has been made at this time to go into detail pending formation of the general program.

Following is a list of some of the references, together with a brief outline of the subject matter covered:

Hazards and Safety Measures at Sewage Works, by Paul J. Houser—Sewage Works Journal, July, 1938.

Covers the danger of infection by disease organisms, danger of accidental injuries, and the danger of poisoning from gases, fumes and vapors.

Safe Handling of Gas at Sewage Works, by L. L. Langford—Sewage Works Journal, January, 1940.

Safety in Sewage Disposal Plants, by N. W. Hartz—Sewage Works Journal, January, 1940.

Covers dangers of gases in sewage plants, together with methods of detection and handling.

Safety Measures for Sewers and Sewage Treatment Plants, Joint Committees of the New England and New York Sewage Works Associations for the Preparation of the Safety Code Relating to Hazards in Sewers and Sewage Treatment Plants—Sewage Works Journal, May, 1940.

Covers:
1. Safety features in the design of sewers and sewage treatment plants.
2. Protective measures to be followed in the operation of sewers and sewage treatment plants.
3. Safety Code.

Proposed Regulations to Insure Safety in the Maintenance, Operation and Reconstruction of Sewers—Committee Report of the California Sewage Works Association.

Covers:
1. Precautions against traffic.
2. Dangerous gases.
3. Aeration of sewers.
4. Apparatus.
5. Resuscitation.
6. General rules.

Orders of the Industrial Accident Commission of the State of California Electrical Safety Orders, 1934; Mechanical Power Transmission Orders, January, 1937; and Dusts, Fumes, Vapors and Gases Safety Orders, November, 1939
General Safety Rules and Regulations, Shell Oil Company, Manufacturing Department.

Covers:
1. Fire prevention rules.
2. General safety rules.
3. Clothing and protective equipment.
4. Permit to perform hazardous work.
5. Railroad equipment and automotive equipment.
6. Procedure in case of accident.

Sewage Treatment Works, by Keefer, Chapter 29, Health and Safety at Sewage Works.

Covers:
1. Electrical power hazards.
2. Hazards caused by infectious nature of sewage.
3. Hazards caused by gases.
4. Explosion hazards.
5. General habards.

Articles by Mr. Van Kleeck of the Connecticut State Health Department, in Municipal Sanitation starting May, 1937.

American Red Cross First-Aid Textbook.

PROGRESS REPORT OF COMMITTEE ON AWARDS

Gentlemen:

Your committee has prepared an invitation to be sent to all eligible communities inviting them to enter their treatment plant in competition for the Annual Award of Merit.

It is planned that this invitation will be in the mail sometime within the next nine days.

Respectfully submitted,

ALBERT J. CASTRO, *Chairman*
Committee on Awards.

REPORT OF MEMBERSHIP COMMITTEE

The Membership Committee wishes to report the following:

Total membership January 1, 1941	281
Members resigned or deceased	3
Members delinquent in dues	60
New members	11
Total Membership March 20, 1941	229
Subscribers to the C.S.W.A. Journal	4

The committee hopes to reduce the number of delinquent members by sending them a third reminder.

Your letter to each member of the Association requesting names of men who should be members has brought forth fourteen suggestions so far. An individual letter inviting each to join the Association has been sent to these persons.

In prospecting for new members the committee has decided to find out where the "nuggets" are before making the dirt fly. A list is being compiled giving the name of every person in California who should be a member. Mr. Gillespie has generously offered to make available the names obtained in a recent survey of sewerage systems and treatment plants. With this list as a working basis, the committee expects to contact each one by a form letter and then wherever possible by a personal call by one of the committee. This program is much more than we can expect to accomplish this year, but it does offer a rich "claim" on which we can do a little "planning" each year.

Respectfully submitted,

JACK H. KIMBALL,
Chairman Membership Committee

OPERATING PROBLEMS IN OTHER STATES AS COMPARED WITH THOSE IN CALIFORNIA

By **T. R. HASELTINE***

Sanitary Engineer with R. E. White, Consulting Engineer, Bakersfield, California

Your committee has asked me to discuss operating problems in other parts of the United States, presumably, because of the fact that during the past twelve years I have been more or less closely connected with the operation of seven different sewage treatment plants in four different states. I doubt if my limited experience in four out of the forty-eight states qualifies me to discuss such a broad field. Therefore, I shall limit my remarks to the states in which I have had the most experience.

First, mention may be made of some of the differences in operating problems in other states as compared with those in California. Most of those differences may be summarized as temperature, rainfall and industrial wastes.

I could cuss and discuss (mostly cuss) the difficulties of rotary filter distributors that will not rotate because of ice accumulations on filter surfaces, or screw grit conveyors that must be defrosted before they will convey, or ice that causes conveyor and clarifier chains to jump sprockets, or snow that sifts in on your car ignition system so that you can't even get home and forget your troubles, but I doubt if such a discussion would be of any practical value. However, some consideration should be given to sewage temperatures. For example, at Salinas, California, I found sewage temperatures to range from 69° during the winter to 75° during the summer, while at Butler, Pennsylvania the range was from 46° to 70°. Sewage temperatures have a marked influence on the functioning of oxidation processes as well as upon sludge digestion and this fact must not be lost sight of in comparing results obtained by biological processes in different parts of the country. It is reported that trickling filters are most efficient at sewage temperatures of 80° to 90° and that their efficiency falls off rapidly with sewage temperatures below 50° to 60°.

Rainfall differences have many effects on operating problems. For example, western Pennsylvania has two to three times the average annual rainfall of central California but it is distributed very uniformly over the entire year. In effect the year around precipitation there is about what you normally have here during the winter. Despite prohibitive ordinances and State Health Board rulings numerous roof leaders are connected to so called separate sewerage systems in most of the cities. As a result sewers receive a thorough flushing almost weekly. I believe that this, at least partially, explains the general absence of hydrogen sulphide problems there comparable with your problems in California. While operating a chemical coagulation plant at Butler, Pennsylvania, I noticed a marked decrease in both chlorine and coagulant demands for a day or two after each heavy rain, followed by

*Formerly Superintendent of Sewage Treatment at Butler and Grover City, Pennsylvania.

a gradual increase in chemical requirements up to the time of the next rain.

Here in the west treated sewage is frequently of value for irrigation so sewage treatment and water conservation go hand in hand. In the eastern states treated sewage is of no value and treatment plants are built solely for the purpose of reducing stream polution. Thus it might be said that there they strive to take the filth out of the water while here you endeavor to take the water out of the filth. The smart operator of an eastern plant keeps a close check on the condition of his receiving stream. Frequently he can cut operating costs by taking advantage of high stream flows or low temperatures.

During the winter the eastern precipitation is largely in the form of snow. Then when thaws come, frequently accompanied by rain, the run-off is very heavy. Unless sewers are particularly well built excessive infiltration is encountered. I operated an activated sludge plant at Grove City, Pennsylvania, where the normal flow was about 0.5 M.G.D. of fairly strong sewage from 7,000 people and a creamery with a raw milk intake of 16,000 lbs. per day. Despite the strength of this sewage we encountered very little difficulty with the process during the summer months. During February, March and April infiltration increased the sewage flow to about 2.0 to 2.5 M.G.D., but, due to plant hydraulics, only 1 M.G.D. could be aerated. The settled sewage contained 2 to 3 p.p.m. of dissolved oxygen. One would anticipate no trouble with the activated sludge process on a reduced loading of such fresh, dilute, sewage after successfully handling the strong summer sewage, but trouble we had. Weekly microscopical examinations of the sludge revealed a steady increase in a species of filamentous growth although goodly numbers of higher protozoa and some rotiferia were also present. Bulking set in and in twenty days the sludge index increased from about 200 to more than 1000. The literature contains many references to the bulking of activated sludge by filamentous growths identified as species of Sphaerotilus. Invariably the true Sphaerotilus growths were encountered during periods of septic sewage flows, heavy organic loads or insufficient aeration. In all such cases there was a marked reduction in larger protozoa and a total absence of rotiferia. All of which is the direct opposite of our Grove City conditions. A high powered microscope showed numerous structural differences between our "bug" and that technically described as Sphaerotilus. We tentatively identified our growth as a species of Leptothrix, but even calling him by that high sounding name wouldn't scare him away and we could find no help in any available literature. Working more or less blindly on the principle that since our "bug" appeared to be the direct opposite of Sphaerotilus the corrective treatment should be the opposite as well, we turned from 800 to 1400 cubic feet per day of very poor digester supernatant directly into the aerators. After nine days of such treatment the sludge index was back down to 200 and we kept it there by the continued additions of about 500 cubic feet of supernatant daily. This experience was encountered in the spring of 1939. The following spring our Leptothrix reappeared but we "shot" it with supernatant immediately and avoided any serious bulking. The Grove City supernatant liquor contains more than 1% total solids during the winter months. Perhaps a good supernatant liquor would have worked just as well, I don't know. But, at any event, it was the first, and only, time I have been grateful for a poor one.

Industrial wastes cause different problems in various parts of the country. Milk wastes are a common problem in almost any state. Cannery wastes are almost, if not quite, as serious in many other states as they are in California. In many localities through the middle west meat packing wastes constitute the most serious problem. Thus, at Topeka, Kansas, we had a 5 M.G.D. activated sludge plant where 20% of the flow and 40% of the equivalent population loading was contributed by the meat packing industry. The packing plant wastes received no pretreatment and caused several interesting problems. For example, these wastes were so hot that monthly average sewage temperatures never fell below 60° although most of the system consisted of combined storm and sanitary sewers. In the summer sewage temperatures were above 85° and odor control was a real problem. (Several years ago one of the operators attempted to solve this problem by hanging containers filled with deodorants such as are commonly found in public rest rooms from the bridges of Dorr traction clarifiers. Needless to say the treatment was unsuccessful.) Grease accumulations in the Topeka pump station wet wells and at the treatment plant were so heavy that the City was able to have the skimming done by outside men who took, as their pay, the scum so collected. Paunch manure caused so much scum in the old type Dorr digestion tanks that those tanks had to be operated by observing the loading in the scum breaker arms rather than from sludge soundings and analyses. Due to the nitrogenous character of the packing house wastes considerable trouble was encountered with activated sludge that settled readily but was lifted again in large brown chunks due to entrained nitrogen gas. This trouble was best controlled by increasing the suspended solid content of the mixed liquor. I understand that our troubles at Topeka were mild in comparison with those encountered at Huron, Sioux Falls, Cedar Rapids, Wichita and various other places where the ratio of packing house wastes to domestic sewage was considerably higher than at Topeka.

In western Pennsylvania mining and metalurgical wastes introduce several problems not commonly encountered here. All steel as it leaves the rolls of a steel mill has more or less scale adhering to it. More and more steel products are being freed of scale by submerging them in dilute sulfuric acid, termed pickle liquor. The acid attacks the iron and forms ferrous sulphate. When the acid becomes too weak the spent pickle liquor must be replaced by a stronger acid. This spent pickle liquor is the most common metalurgical waste. It has been estimated that the annual production of this waste in the United States ranges between 500,000,000 and 800,000,000 gallons. Its average composition is 15% ferrous sulphate and 3% sulfuric acid with small quantities of other materials.

Iron pyrites occurs in, above and below soft coal strata in Pennsylvania and elsewhere. As mines are opened and air comes in contact with the pyrites it is oxidized and dissolves in the water draining from the mine. The pyrites, oxygen and water combine to form ferrous sulphate and sulfuric acid, the same ingredients found in the spent pickle liquor. The drainage from abandoned coal mines is as acid as that from active mines, if not more so, because the pyrites is frequently most plentiful just below the coal strata.

All mine drainage and some of the spent pickle liquor enter the streams with no treatment. They destroy fish life and frequently deposit a brown, iron hydrate, sludge on the stream beds due to further oxidation and alkali-

zation by other waters. Pollution resulting from fluctuations in volume and strength of acid wastes may cause great hardship in water purification, especially in those streams which are ordinarily near neutral. Although an acid water may be neutralized chemically its hardness is increased. It may then be softened, but if the original acidity was too high the chemicals remaining in solution will cause foaming and priming in boilers. However this form of stream pollution may be a boon to the sewage plant operator because the wastes inhibit bacterial action as well as fish life. Pittsburgh, with a population of 700,000, discharges all of its sewage in an untreated state into the Allegheny, Monongahela and Ohio Rivers which join at Pittsburgh. Surveys by the Pennsylvania Health Department on the Ohio River just below Pittsburgh reveal the surprising fact that its bacterial count and B Coli index are lowest during periods of minimum stream flow. Reason:—At such times the concentration of acid wastes is the highest. There are several smaller cities getting by with little or no sewage treatment because of the acidity of their receiving streams.

Recently three factors have combined to reduce the acid pollution of Pennsylvania streams: (1) Curtailment of the discharge of untreated spent pickle liquor into the streams by the enforcement of state laws; (2) extensive W. P. A. projects to seal abandoned coal mines thereby preventing the contact of air with the pyrites; and (3) the construction of flood control dams on the Ohio River water shed that store up relatively clean water from spring freshets for discharge during periods of minimum stream flow. As these projects progress expenditures for water treatment will drop and those for sewage treatment will increase.

When a steel mill can not discharge its spent pickle liquor directly into a stream it usually adopts one of the following three methods of disposal (a) dumping into city sewers; (b) aeration and neutralization with lime followed by sedimentation, usually in lagoons, and (c) the recovery of the ferrous sulphate which is disposed of as copperas or converted into some other iron compound. Despite several years research at Mellon Institute, financed by the iron and steel industry, no economically self supporting means of treatment has been found. A few large mills use the third method of recovering iron salts, but if more mills followed that method the market for iron salts would be flooded. A few large mills have attempted to make building materials from the sludge resulting from the lime treatment with some success. In general, however, the steel mills have to write off the entire cost of spent pickle liquor treatment as a total loss.

In a very few cases sewage or water treatment plants have been able to take a part of the spent pickle liquor, neutralize the acid with scrap iron, and use the resulting ferrous sulphate solution for chemical coagulation. It is indeed a rarity, however, when enough of the liquor can be so utilized as to materially reduce the steel mill's problem. The literature contains several references to the chemical coagulation of sewage with ferric iron salts at a pH as low as 2.5 to 4.5. When I first started operation of the Butler plant I had visions of chlorinating the pickle liquor without neutralizing the acid and using it as a coagulant. However, a number of laboratory trials gave very erratic results and so we gave up the idea. Later Rudolfs and Gehm showed that for effective coagulation at low pH the acid should be added after the ferric iron—not with it.

A comparison of results obtained at Butler and Sharon, Pennsylvania, may be of interest to illustrate some of the problems resulting from the introduction of spent pickle liquor directly into city sewers. Both are cities of about 27,000. Both built their original sewage treatment plants in 1926-27, and both lay claim to having the first separate sludge digestion plant in the state. Neither plant provided for gas collection. Late in 1938 both cities took advantage of P. W. A. grants to extend and improve their plants and both cities employed the same consulting engineer. The new designs, in both places, called for new digestion tanks with gas collection and gas engine driven generators capable of supplying all necessary power. Much to my envy Sharon provided two engines, one for stand-by service, while Butler got only one. Both cities had two industries discharging spent pickle liquor. Both of the Butler industries treated their own wastes prior to discharge into the stream. The Sharon industries were smaller and in order to keep them going the City saw fit to permit them to discharge their spent pickle liquor directly into the sewers. Both new sewage plants were started up at about the same time. During the first year at Butler we operated our engine 85% of the time and generated 83% of all our power at a saving of $1800.00. At Sharon their gas production was so low that they never operated either engine except for testing purposes. At times the sludge run onto the drying beds at Sharon was actually brown because of its high iron content. The last reports from Sharon were that the City officials, the designing engineer, the steel mills and the State Health Department were in a close huddle.

Up to the time I came to the Butler sewage plant it had been the practice to use ferric chloride as a coagulant in order to increase the plants efficiency during the summer months. I found that one of the local steel mills was producing copperas from their spent pickle liquor and would sell us all we could use for about 60% of the market price of commercial sugar copperas. Their copperas was slightly acid and contained some large chunks. It rotted sacks in a few weeks time and could not be handled in the ordinary dry feed chemical machines commonly used for feeding commercial sugar copperas. We rigged up special equipment for dissolving, feeding and chlorinating this material and so were able to obtain equivalent ferric iron at a cost of $4.16 per 100 lbs. as compared with $13.05 for ferric iron from commercial anhydrous ferric chloride as previously purchased by the City.

Despite that cooperation from the steel mill they did cause us serious trouble in another respect. They were located between the city proper and the sewage plant. They took water from Conoquenessing Creek, our receiving stream, into their plant to cool their rolls and then returned it to the Creek just above the point where we discharged our treated sewage. During periods of low stream flow they used a large proportion of the total flow for that purpose. Last August and September creek analyses above the point of their intake showed averages of 79° F. temperature, 7.9 p.p.m. dissolved oxygen and 1.3 p.p.m. of 5 day B.O.D. Below their plant, but just above our outfall, the creeks temperature was 95° F.; its dissolved oxygen only 4.5 p.p.m. and its 5 day B.O.D. 4.3 p.p.m. In addition it was frequently covered with a light film of oil that effectively curtailed reaeration down stream. Believe me, treating sewage for discharge into such a stream is just like having two strikes called on you before you come up to

bat in a baseball game. That condition explains why chemical treatment did not prove adequate for Butler's sewage and why the sewage plant had to be expanded to include trickling filters.

I might sit down now, or I might go on pointing out other differences between Eastern and California operating problems, but, instead, I want to mention some of the similarities in those problems. The first parallelism is we, ourselves, the operators. A real "top-notch" sewage plant operator should know almost everything that the plant designer knows, with the possible exception of structural design, and he must know many other things besides. It goes without saying that few of us can qualify as "top-notch" but, at least, we are all trying to improve or else we wouldn't be here. So let's take a look at our job:

Now there are just plain lazy operators. I knew one once who used to keep his guitar out at the plant. He said "it was a good place to practice and gave him something to do with his time." Well, after hearing him play, I agreed that it was a good place for him to practice, although not quite isolated enough. However, any house-wife could have pointed out 101 other things for him to do with his time. Also, I recall plant libraries that contained more western and detective magazines than Sewage Works Journals. I admit there are more published, but that hardly justifies their presence in a sewage plant. But let us "fire" the lazy man and think about the honest, hard-working operator. He must be all of the following: chemist, janitor, mechanic, gardner, accountant, laborer, electrician, watchman, public relations man, dishwasher, pipe fitter, just plain "sewer rat" and carpenter. He must know something of such unrelated subjects as bacteriology, hydraulics, therodynamics, salesmanship and still, and withall, not be afraid of getting his hands dirty; his only legitimate "kick" is when sludge gets in his eyes or mouth. Now, we wouldn't be human if some of these callings didn't appeal to us more than others did. Personally I have always enjoyed laboratory work, but, at first, I knew or cared nothing about machinery. To this day I have to drive myself to get in and study every piece of mechanical equipment in a plant until I thoroughly understand how and why it works, but sad experience has taught me that such knowledge is essential. Another fellow just can't be happy unless his hands are covered with oil and grease up to his elbows, but he will let the flies and spiders fight it out in the laboratory. I knew of at least one plant that had beautiful green lawns, well trimmed shrubbery and lots of flowers, but you could hardly tell the effluent from the influent by either sight or smell, there were no records and the 600W in a speed reducer had not been changed since the contractor poured it in four years previously. I once had an ex-bartender working under me who didn't like to do anything but scrub and polish. Boy! how he could make anything from a beaker to a gallery full of black cast iron pipe shine. I lost him when repeal came in.

I won't say that chemistry is more important than machinery or that cleanliness and neatness is any less important than either. The point is, that they *all* have to be tended to whether we enjoy it or not. If you are lucky enough to have several assistants under you it is possible to divide the work so that each of them can devote the bulk of his time to doing that which he is best suited for *but* you, as chief, must pay attention to *everything.* If you don't your assistants will become careless.

It has been my experience that the best way to avoid missing something is to have a schedule for your own time and for each of your assistants. Read meters at the same hour each day. Take samples according to routine—maybe it will be every hour of the twenty-four, seven days a week, or maybe it will be every hour for an eight hour period on Tuesdays and Thursdays, but follow a schedule. Sample digestion tanks from top to bottom at regular periods. I have always done it once a week, perhaps semi-monthly would be often enough. Follow a regular routine in your laboratory work; it is a great time saver. Start pumping sludge at the same hours each day. Skim tanks at regular intervals. Your schedule should provide certain hours of certain days for care of grounds, other periods for cleaning sludge beds, etc. Greasing can be segregated into daily, weekly, monthly and semi-annual schedules but go to the trouble of actually making up the schedules. Daily greasing and inspection should be done at the same hour each day; weekly greasing on the same day of each week and so forth. Your routine should include a definite period in each week for general plant clean-up. You may ask what happens to this schedule when a chain breaks, a bearing burns out, a heavy storm floods your plant or visitors swarm in on you. Well, of course, your routine is disrupted but, at least, you know you are behind and can work that much harder to catch up. Without a schedule you come down to your plant in the morning and, if no accident appears on the scene, you look around for something to do. Not being lazy, you have no trouble finding that something, but it will probably be the thing that interests you most. You will become engrossed in it. The first thing you know the day is gone and something that should have been tended to has been neglected. Routine is the first "R" of sewage plant operation.

The second "R" is records. I know that some fellows just naturally fight shy of a pencil, but they can get over that failing. A printed form is even more awesome. I used to make up forms for assistants to keep records on and it nearly scared some of them to death. I remember one fellow who actually claimed he was going blind simply because I sprung a new form on him. I have had better success by telling the men what I wanted to keep a record of and letting them make up their own forms. After a few days they could usually see plenty of defects in their forms and then I could help revamp them. Don't depend upon your memory for anything; make a record of everything from Joe getting a sliver in his thumb to buying a new sewage pump. A diary is essential and your schedule should include a definite time each day for writing in it. In Pennsylvania the State Health Department insisted that each plant file weekly operating reports. They let the individual plant superintendents draw up their own report forms, but did make certain pertinent suggestions as to what should be included. The records for different plants ranged all the way from complete chemical and bacteriological reports on the character of the sewage at some of the larger plants to simple records of sewage flow and time the sludge pump was operated at some of the smallest plants. I seriously doubt if the state engineers read all these reports as they came in, but they did keep check on whether or not they came in, and always acknowledged their receipt. That kept the plant operators on their toes.

The ideal record form has a blank for recording every conceivable observation that there is any likelihood of the operator making. But don't fill

in all the blanks just because they are there, unless you actually made all the observations. When I first came to Butler in April, 1937, I was added to the force without displacing any of the regular operating crew. I asked them to continue on just as though I was not there. At the end of the first week I noticed that the report to the State showed the pH of the sludge in each of the fourteen compartments of the digestion tanks although I was certain that no samples had been taken. I inquired and was told that the tank had been sampled some time last October and that the pH didn't change much! The only thing worse than no records at all are false records.

Now you fellows who dislike laboratory work will probably argue that you can take samples and weigh gooch crucibles until the scales are worn out without changing the performance of a sedimentation tank one iota. "If it is just a mess of figures you want why not use the phone book instead of going to all the trouble of collecting some new ones in the laboratory?" The answer to that argument is the third "R" of sewage plant operation, namely retrospection. Anybody's hind-sight is better than their fore-sight so provide some time in your schedule to just sit and look back over your records. Hunt for changes in the performance of your plant; next, try to figure out from your records and your general experience why those changes took place; then you are in a position to improve your plant performance. Study of the other operators' experiences as published in technical literature is a great help in this job, but all the data ever published are worthless to you, personally, unless you view them in the light of your own records. If this retrospection is conscientiously done you will have no doubt about the value of records; your only regret will be that you didn't keep more complete ones.

Masses of figures are hard to comprehend and daily results vary over such wide limits that usually trends can be observed only from averages or medians of many daily records. It is a tedious job to figure averages over any protracted period. I have found it simpler to average each week's results at the end of that week. Four weekly averages may be easily averaged again for monthly results. If a regular routine has been followed each week the averages so obtained are mathematically correct.

The operator is hired, primarily, to keep his plant running, but just because it runs one way is no sign that it would not run better some other way. Any well designed plant is arranged for several alternative modes of operation and the operator should determine when and why each particular scheme should be used. If a process or piece of equipment does not work at all we are quick to do our best to correct the trouble, but we are very prone to let anything that is working at all "plug" along until it quits. I believe that a good operator should be as quick to learn why his plant works as he is to learn why it does not. I don't mean that he should deliberately tear a piece of equipment up or overload a process just to see what happens, but, coming back to records and retrospection again, coupled with study of technical literature and any small scale experiments he can make, he may be able to find out not only why it works but how it could be made to work better.

Partly by way of illustration and partly because I desire your opinions, I wish to summarize briefly ideas I have formed regarding the drying of sludge on sand beds. Despite the fact that until recently almost every sewage plant had sludge drying beds no phase of sewage treatment has received

less scientific treatment or less mention in operating reports. I have made attempts to study the problem off and on for ten years. There always seemed to be so many variables that it was impossible to ascribe a result obtained to any single factor. Finally I came to the conclusion that the units used to measure the performance of sludge beds were all wrong. The three units most commonly used are as follows:

(1) "Number of fillings per year;" this is meaningless unless correlated with the depth of the fillings and the solid content of the sludge.

(2) "Cubic yards of wet sludge drawn per year;" this must be correlated with bed area and sludge solids to have any significance.

(3) "Pounds of solids applied per square foot per year;" this is more scientific than the other units but the mere fact that beds handled 25 lbs. of dry solids per square foot per year does not mean they could not have handled 40 lbs. if more sludge had been available or if beds had not been idle part of the time.

It appeared to me that a more logical criterion would be *the pounds of dry solids applied per square foot per 30 days of actual bed use.* I have called this unit the *"bed loading."* For example, if sludge containing 10% solids is applied 12″ deep and removed after 40 days the "bed loading" is $\frac{62.5 \times 10\% \times 30}{40}$, or 4.69 lbs. per sq. ft. per 30 days. (Note: theoretically these results should be multiplied by the specific gravity of the wet sludge but because of the paucity of specific gravity records I have omitted that refinement.)

Table I shows "bed loading" at fourteen different plants over periods of from 1 to 14 years. Geographically the plants included range from Salinas, California, to Huntington, Long Island, and from Rochester, New York, to San Antonio, Texas. However, as a concession to weather effects, I have excluded, whenever possible, the winter months at the northeastern plants. The Table includes primary sludge, chemically precipitated sludge, primary and filter humus sludge, and primary and activated sludge digested in Imhoff tanks, single and two stage digesters heated and unheated and applied in various depths to open or glass covered beds. In some cases alum was used to aid sludge drying.

In Figure I these "bed loadings" are plotted against the solid content of the applied sludges. Despite numerous scattering there appears to be a definite, direct, relationship between the solid content of the applied sludge and the bed loading. That relationship may be expressed by the formula $Y = 0.96X - 1.75$ where Y is the bed loading and X is the percent solids in the applied sludge. It should be pointed out that this finding is in direct contradiction of statements made by Downes[8] in 1931, but in 1934 Jones[7] questioned the general application of Downes' findings.

Table I shows that the solid content of the sludge removed from the beds ranged from 62.8% to 24.5%. Naturally the lower the solid content of the sludge removed the shorter will be the time on the beds and, hence, the higher the bed loading. Slight variations in solid content of sludge removed may be of little significance, but wide variations affect the cost of cleaning beds and the amount of sand replacements required. Observations

at Butler in 1938 indicated that the number of square feet of bed area cleaned per man-hour was about 98 for 25 to 30% solids sludge; 135 for 40 to 50% solids sludge, and 180 for 60 to 70% solids sludge. At Dayton[1] Tatlock found the removal costs per ton of dry solids to be $1.26 to $1.95 for 36 to 37% solids sludge and only $0.71 to $0.77 for 48 to 56% solids sludge.

In order to take into consideration the variable of solid content of sludge removed, we propose, as a second unit (termed *"bed efficiency") the product of the "bed loading" multiplied by the percent solids in the sludge removed.* It is recognized that it will require more than twice as long to produce a sludge of 60% solids as it does to produce one of 30% solids. However, it is believed that the ability to dispose of sludge is of greater importance than the production of a high solid content sludge and, therefore, from a practical operating viewpoint, this proposed "efficiency" unit may give about the correct weight to all factors.

In Figure II the bed efficiencies of Table I have been plotted against the solid content of the applied sludges. Inspection shows that most of the points conform quite closely to the formula $Z = 0.35X - 0.5$ where Z is the "bed efficiency" and X, as before, is the percent solids in the applied sludge. The wide range of plants and sludges included and the reasonable conformance of the data to the empirical formulae given justify, in the writer's opinion, the conclusion that *the solid content of the sludge applied to drying beds is the most important single factor influencing bed performance.*

A study of some of the points that do not conform to the above formulae is enlightening. In Figure I there appear to be six classes of non-conformance:

Table I

Sludge Drying Bed Performance

Plot Point	Plant	Year	Sludge Solids Applied	Sludge Solids Removed	Bed Loading	Bed Efficiency	Reference
a	*Butler, Penna. . . .	1937	9.2	37.9	4.95	1.88	Plant Records
	" " . . .	1938	8.3	34.9	5.71	1.99	" "
	" " . . .	1939	5.8	52.5	3.07	1.61	" "
b	" " . . .	1940	8.15	34.7	4.07	1.39	" "
c	Cleveland, Ohio . . .	1930	12.0	56.0	7.50	4.20	(2)
d	" " . . .	1931	13.0	42.0	6.82	2.86	"
	" " . . .	1932	10.0	37.0	8.06	2.98	"
	" " . . .	1933	9.0	30.0	7.28	2.18	"
	" " . . .	1934	8.0	35.0	6.04	2.11	"
	" " . . .	1935	9.0	43.0	5.84	2.52	"
	" " . . .	1936	9 0	45.0	6.43	2.90	"
	" " . . .	1937	9.0	40.0	6.38	2.80	"
	Dayton, Ohio	1931	4.08	37.0	3.75	1.39	(1)
	" "	1932	5.06	36.0	4.75	1.71	"
	" "	1933	4.72	48.5	2.27	1.10	"
	" "	1934	4.87	56.0	1.85	1.04	"
	Great Neck, N. Y. . .	1937	4.5	32.3	2.04	0.66	(3)
	*Grove City, Penna. . .	1938	4.75	....	1.95	....	Plant Records
	" " " . . .	1939	3.60	38.6	2.02	0.78	" "

Table I—Sludge Drying Bed Performance—Continued

Plot Point	Plant	Year	Sludge Solids Sludge	Solids Applied Removed	Bed Loading	Bed Efficiency	Reference
e	Huntington, N. Y. . .	1937	8.4	27.0	10.80	2.92	(3)
k	*Lancater, Penna. . .	38-39	2.80	24.5	1.76	0.44	(4)
g	Marion, Ohio	1929	7.15	32.3	6.18	2.00	(7)
f	Port Washington, N. Y.	1937	4.70	26.0	7.95	2.07	(3)
	*Rochester, N. Y. . . .	1922	10.2	....	6.95	....	(5)
	" " . . .	1923	8.4	....	7.43	....	"
	" " . . .	1924	10.0	....	7.48	....	"
	" " . . .	1925	9.2	....	8.64	....	"
	" " . . .	1926	9.2	....	5.07	....	"
	" " . . .	1927	8.1	....	6.32	....	"
	" " . . .	1928	6.5	....	3.50	....	"
	" " . . .	1929	7.3	....	5.68	....	"
	" " . . .	1930	7.2	....	4.95	....	"
	" " . . .	1931	6.3	....	4.75	....	"
	" " . . .	1933	6.0	....	4.52	....	"
	" " . . .	1934	7.0	....	6.52	....	"
	" " . . .	1935	6.6	....	4.42	....	"
	" " . . .	1936	6.4	....	4.58	....	"
j	Rockville Centre, N. Y.	1937	5.4	24.5	6.78	1.66	(3)
m	Salinas, Calif. . . .	32-33	5.4	62.8	2.15	1.35	Plant Record
	San Antonio, Texas .	....	4.0	45.5	1.90	0.86	(6)
h	Springfield, Ill. . . .	1932	9.2	54.1	4.93	2.66	Annual
	" " . . .	1933	8.4	....	3.50	....	Report

*7 to 9 months drying season; other plants 12 months.

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(3) Sewage Works Journal, vol. 10, page 503, May, 1938.
(4) Municipal Sanitation, vol. 11, page 140, March, 1940.
(5) Sewage Works Journal vol. 10, page 153, January, 1938.
(6) Water Works and Sewerage, vol. 80, page 123, 1933.
(7) Sewage Works Journal, vol. 6, page 1117, November, 1934.

(1) Points e, f, j, and k (Huntington, Port Washington, Rockville Centre and Lancaster) show unusually high loadings which are believed due to the low solid content of the sludge removed, 27.0, 26.0, 24.5 and 24.5% respectively. In Figure II these points are much closer to the general average although the first three are still high. This shows what can be done in the way of crowding beds when necessary. It must be remembered, however, that the costs of cleaning and sand replacements are increased by such a practice. It is the writer's opinion that the operator should endeavor to obtain as dry a sludge cake as possible consistant with handling the accumulated digested sludge. Idle beds are serving no purpose. At Butler and Grove City we kept our beds loaded 80 to 90% of the time the year around. When operating the Salinas plant in 1932-34 we followed the same practice despite the fact that the bed area was large for that climate and we frequently had as high as 90% solids in the sludge removed. We know of no justification for removing sludge from beds with only 26% solids 6 to 7 days after application and then letting the beds stand idle 80 to 84% of the time as is done at Port Washington, point f; Huntington, point e, is in the same category for there the sludge is removed after 12 days with only 27% solids and the beds stand idle 60% of the time.

(2) Points c, m and h (Cleveland 1930, Salinas and Springfield 1932) are the direct opposite, and show low loadings which are believed due to the high solid content of the sludge removed; 56.0, 62.8 and 54.1% respectively. In Figure II points m and h are almost in direct conformance.

(3) Point c, Cleveland 1930, falls considerably above the line in Figure II despite the fact, just noted, that it is below the line in Figure I. Referring to the

original data we find the average air temperature at Cleveland during that year was 61° F. while the next highest annual temperature was 55° F. and the average of the seven other years was 53° F. It is only logical to expect increased efficiency at higher temperatures.

(4) Point d, Cleveland 1931, falls considerably below the line in both figures. This point represents a solid content of 13% in the applied sludge. It seems probable that the empirical formulae developed do not apply to such heavy non-fluid sludges although more data are needed to confirm this conclusion.

(5) Point a, Butler 1937, also falls considerably below the line in both figures. The writer first took charge of the Butler plant in that year. Despite the fact that the plant was provided with a grit chamber we found large amounts of grit passing into the sedimentation tanks and thence to the digestion tanks during every storm. In November of that year we altered the grit chamber and doubled to trebled the amount of grit collected. The non-conformance of this point is believed due to the excessive amounts of grit in the applied sludge.

(6) Point b, Butler 1940, is considerably below the line in both figures. Late in November 1939 we put into operation a new digestion tank and utilized the gas collected therefrom for power production. Since our old tanks were not arranged for gas collection we fed all fresh sludge (2 to 5% solids) to the new tank and ran its overflow (0.3 to 3.0% solids) into the old tanks where it settled out to a clear supernatant of 0.17 to 0.24% total solids for return to the raw sewage. During 1940 76% of all sludge applied to the drying beds was drawn from the old tanks. Table II shows the characteristics of the sludge drawn from each tank and its drying qualities. Although the sludge from the old tanks contained 8.8% solids as compared with 6.6% in that drawn from the new tank it did not dry as well. Our records showed the bed loading and efficiency with the sludge from the old tanks to be 3.89 and 1.35 respectively; these are only 58 and 52% respectively of what we should have obtained if the above formulae applied. On the other hand, the bed loading and efficiency with the sludge from the new tank was 4.50 and 1.56 or 98 and 86% respectively of the values computed from the formulae. This indicates that although storage of digested sludge increases its solid concentration it does not improve its drying characteristics and may actually detract from them. This agrees with the laboratory findings of Rudolfs and Heukelekian[9] and constitutes one serious disadvantage to the use of stage digestion.

Table II

Sludge Drying, Butler, Pennsylvania, 1940

Digestion Tanks Drawn From	*New Primary*	*Old Secondary*
Alkalinity of applied sludge	2842	3255
% solids in applied sludge	6.6	8.8
% volatile in applied sludge	45.2	43.8
Depth applied to beds, inches	9	9
Average drying time, days	20.6	31.7
% solids in sludge removed	34.7	34.7
"Bed Loading"	4.50	3.89
"Bed Efficiency"	1.56	1.35
Number of beds drawn	16	38

The writer believes that if more were known about local conditions that the non-conformance of many of the other points could be somewhat similarly accounted for. It is interesting to note how close point g conforms to the formula in each figure. This point represents results obtained at Marion, Ohio in 1929 with two glass enclosed beds that were given special attention so that sludge was always removed as quickly as economically feasible and the beds never remained idle.

It would be desirable to have sludge bed performance criteria that took into consideration the effect of temperature but pending the development of

such a criterion it is believed that the units of "bed loading" and "bed efficiency" as herein defined are a marked improvement over criteria in common use. The formulae developed are purely empirical and probably will require some change when more data become available. The writer has used the new criteria to study optimum depths of wet sludge applications to drying beds at Butler and Grove City, Pennsylvania, the value of alum as an aid to sludge drying at both plants, the value of activated carbon for the same purpose at Grove City and the relative merits of open and covered beds at Grove City, all with considerable success. However, the conclusions arrived at are believed to apply primarily to those individual plants and so are excluded from this paper.

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CROSS CONNECTIONS IN SEWAGE PLANTS

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The subject of cross connections has been of particular interest to sanitary engineers for a number of years. In 1930, the Surgeon General of the U. S. Public Health Service issued instructions to all State sanitary engineers to refuse certification to water supplies where cross connections existed within the water system. A cross connection is defined as a physical pipe connection between a potable water supply and any other source of water supply or fluid material which may permit the flow of a potentially dangerous material into a potable supply. From the water works standpoint, the first attention in this line was given to wells, salt water, polluted rivers and other secondary sources of water supply. In 1933, an outbreak of amebic dysentery in two Chicago hotels focused attention on the danger of cross connections within building piping. Numerous articles have appeared in the technical journals pointing out the danger of such cross connections. It should be of interest to sewage works engineers and operators to look at their systems and plants for cross connections which may endanger the health of the operators or residents of their communities. The purpose of this paper will be to outline the location of such cross connections as may exist and to suggest remedies for their protection or elimination.

Water works engineers have devoted much time and attention to the protection of their supplies. The source of the water is constantly surveyed for evidence of pollution, the water is carefully treated, constantly tested, and, in most cases, delivered to the consumers in first class condition. All of this

care and expense can be offset by dangerous connections within consumers' premises or by careless handling of the sewage disposal works of a community. A search of the literature will reveal many cases of water supply pollution with attendant outbreaks of disease caused by improper piping or careless handling of equipment.

In September, 1940, the following resolution was adopted by the California Sewage Works Association:

"WHEREAS: Cross connections between water supplies and sewage lines are known to exist at most sewage treatment plants and pumping plants, and

"WHEREAS: Such cross connections are a menace to the safety of the water supply, through possible back-flow and back-syphonage, and

"WHEREAS: There is need for the operators to discover and correct all possible cross connections, including cooling lines to compressors and gas engines, pump priming and water seal lines, submerged inlets, including hoses, water-operated skimming nozzles, chlorinator water feed lines, lines to venturi cleanouts and float wells, and back wash lines to sludge and sand filters: now therefore

"BE IT RESOLVED: By the California Sewage Works Association in convention assembled at San Diego, California, September 17, 1940, that operators of sewage plants, pumping stations, and similar structures be urged to study the problem of cross connections existing in such works, and take such steps as are necessary to protect the water supplies by a break in connection, vacuum breakers, and/or valves designed to prevent back-flow and back-syphonage.

"The foregoing resolution was prepared by the Board of Directors pursuant to unanimous authorization of the membership of the Association in convention assembled at the Hotel U. S. Grant, San Diego, California, on the seventeenth day of September, 1940."

This resolution enumerates a number of places where cross connections may exist in sewage plants. The writer has visited a number of sewage plants recently with the particular purpose in mind of looking for such connections and enumerating them. Their prevalence is indicated by conditions found. In one plant, it was observed that water and sewage connections existed throughout the plant performing a total of thirty-eight different functions within this one plant. In some cases, one operation or function occurred as many as ten or twelve times within the plant. The total number of dangerous connections would, therefore, total a hundred or more. Following is a brief outline of such connections found in this and several other plants visited.

Water is used to some extent in the collecting and transmission works of a sewerage system. Collecting sewers are frequently flushed with a water hose connected to a fire hydrant. These flushing operations are usually not of long duration and are always done in the presence of an operator or other employee but should a partial vacuum occur in the water system during such flushing operations, sewage might readily be drawn into the water system. In many buildings, water connections are made to sewer lines for the purpose of flushing them should a stoppage occur. This is a particularly dangerous practice as sewers are apt to be flushed at any time without supervision or by persons unfamiliar with the dangers attendant. Storm sewers are frequently cleared of accumulated sediment by flushing with fire hoses from fire hydrants. Sand catch basins are sometimes cleared with water or water ejectors and agitators are used to dislodge deposited material. Water-sewage connections in buildings are too numerous to elaborate and are beyond the jurisdiction of the sewerage engineers but should be looked into by plumbing inspectors.

Automatic flush tanks are frequently installed in main sewer lines to flush out deposits of sediment which tend to clog sewers. Most tanks are placed in

the sewer or a manhole where they may become submerged at times of high flow or stoppage of the sewer. The water connection is open all the time and should any partial vacuum occur during submergence, sewage would be drawn into the water system.

As sewage enters the plant, the first operation performed is usually that of screening. Bar racks and screens are usually mechanically cleaned. In some instances, water is used to aid this cleaning operation, either in the form of sprays or wash lines. Spray nozzles are sometimes located in such a position that they may become submerged at periods of high sewage flow. Hoses are sometimes used to wash down racks and are occasionally allowed to drop into the sewage.

Shredders and grinders are also used in connection with screening operations, this equipment usually being washed by sprays, flush nozzles or hoses. In some cases, the ground or shredded material is carried back to the incoming sewage with water.

Meters are used in many places throughout sewage plants. They measure the incoming sewage, sometimes from several sources. The water used around the plant is also metered. Meters are installed at different points about the plant to measure the amount of material being handled, such as, sludge, return or recirculated sludge, influent and effluent from digestors, water and sewage in elutriation process, plant effluent, and for other uses. In most cases, mechanical metering is employed and there is no water connection to the meter. In some cases, however, venturi meters are used and water is employed in the connections to recorders and indicators. In a few cases, flushing water is connected to the meter to clear moving parts of obstructions. These meters are essential and in some cases water connections to meters are essential but in all cases the water should be protected against pollution by sewage.

Water is used for operation of chlorinating equipment, connections being made to injectors, for tray supply and for other uses. Under certain operating conditions, it may be possible to contaminate the water supply with sewage.

Pumps are probably the most numerous pieces of equipment in a sewage works. Sewage is pumped from one point to another in the collecting system, is frequently pumped into or out of the treatment plant. Pumps are used on the influent lines; to remove sand and grit from receiving tanks or sedimentation basins; to remove grease, scum, and other material; are used on raw and digested sludge lines, are used for pumping sludge for seeding digestors, are used to pump effluent around the plant and away from the plant; and to pump filtrate from the treating process. In many cases pumps are equipped with priming lines and water seals. Vertical impeller pumps frequently require priming and in many cases a water line is connected to the pump to fill the case, thus priming the pump before it is started. Water lines are frequently connected to bearings and glands in sewage pumps to prevent cutting and wearing of the bearings by gritty sewage. The danger is always present that sewage may be pumped back into the water lines or may be sucked in by a partial vacuum in the water system.

Clearing sludge lines is a frequent activity in most sewage plants. Sludge deposits build up in pipes and impede or prevent the flow of sludge. In many cases, water connections are made to sludge lines to flush them, removing obstructions and deposits and are sometimes used to thoroughly flush and clean sludge lines when the plant is cleaned or shut down for maintenance operations. Sludge lines are found on sedimentation tanks, sand traps, flocculating basins, raw and digested sludge lines and in mixing tanks. A stoppage of sludge lines

may result in building up fairly high pressures which could force sewage into the water lines.

Sprays are used quite generally in sewage plants to remove scum, grease, and other floating material. Sprays are found on clarifiers, sedimentation basins, grease removal tanks, flow chambers, elutriation tanks and in other places throughout sewage plants. Spray nozzles are customarily installed a few inches above the surface of the liquid in the tank or basin. They may, however, become submerged by stoppage of the drainage or overflow works or may be dropped into the tanks by failure of supporting devices.

Hose connections for washing and flushing are common throughout sewage plants. Hose bibbs are installed in many places and hoses connected to them for general use. Floors and working platforms are washed, basins and tanks are hosed down for cleaning, sludge lines and other pipes are equipped with hose connections for washing or flushing. In many instances hoses are connected to water faucets and left in place for use whenever needed. It is common practic to allow the open end of the hose to drop into a tank or basin and to be left there. The writer observed many such instances in plants recently visited. Sometimes, hoses are used to aid sprays running continuously or intermittently as needed. Hoses are also used for filling equipment and starting operations after a plant has been shut down or drained.

Vacuum ejectors are frequently used around sewage plants for removing water from sumps and drainage basins. Pumps and other equipment are frequently located in pits and when this equipment is drained for maintenance or repair some material drains onto the floor of the pit where it is collected into a sump and a vacuum ejector used to empty the sump. These vacuum ejectors are invariably operated by water pressure. In a few cases air and water are used in combination to prevent the packing of sand or grit in sedimentation basins. These air-water ejectors are operated with high-pressure water.

Water is used in many other ways around sewage plants. Following are but a few of the uses: boiler makeup, digestor heating coils makeup, digestor seals, hydraulic valve cylinders, irrigation of grounds, in the laboratory, in toilets and showers.

It is thus seen from the above outline that the use of water around sewage plants is quite essential and that in many instances water and sewage connections are made in such a manner as to be dangerous to the safety of the water supply. The fact that this danger exists, and is apparent to the operators was noted, in that bottled drinking water is supplied in many plants for the use of the operators and visitors. Under normal operating conditions, the danger of back-siphonage or back-flow from the connections enumerated above is slight. Water pressures are in general much higher than sewage pressures. The sewage plant is invariably located at the lowest elvation in the sewerage system where water pressures are apt to be highest. However, normal operations in water systems frequently require shut-downs for maintenance or repairs, sometimes breaks occur which reduce the pressure in the water system and occasionally fires result in low pressure or even a partial vacuum in the water piping. Sewage is probably the most dangerous material handled in connection with water from a disease standpoint and extreme precaution should be taken to assure continued safety of the water supply. In some cases, it is permissible to install double check valves in a water line where a cross connection exists with another source of supply or with some potential hazard. In the writer's opinion, however, double check valves are not sufficient protection in sewage plants because of the

nature of the material handled. In some cases, double check valves are installed at each of the cross connections with sewage. For example, a small water line connected to the bearings on a sewage pump may be equipped with double check valves just ahead of the connection to the pump or a water line connected to several sludge lines for flushing may be thus equipped. This probably affords partial protection but should not be considered entirely satisfactory. In one case, blank flanges were installed in the water piping and a hose connection made around the blank flange to be used only when flushing operations were actually being made. It has been noted, however, that hoses are usually connected up and left in place between operations thus nullifying the effect of the blank flange. The common practice of allowing hoses to drop into tanks and basins containing sewage and leaving them there may be noted at almost any plant. The ideal situation for any sewage plant is to receive water from the domestic system by free-fall into an open tank and then to repump the water to obtain the desired pressure for water around the plant. This free-fall into an open tank should be through a pipe which is terminated above the overflow level of the tank.

Many sewage plants contain such a maze of piping that anyone not familiar with the design and construction of the plant may find it difficult to determine which are water lines, which are sewage lines and which are chemical lines. Painting these pipes that carry different materials a suitable color is a decided aid in tracing out the piping in the plant. In one plant recently visited, a suitable combination was noted. Here, all sewage lines were painted black; sludge lines were brown; water lines were blue; air lines were white; chemical lines were yellow. In another plant, the entire piping was not painted a distinctive color but a stripe of color was painted around each joint of pipe or fitting. With a system of this kind, it is easy to trace out the piping layout of a plant and to determine just what material is carried by each pipe inspected.

There are on the market some valves mechanically designed to prevent back flow in a safe manner. One such valve is made by a West Coast manufacturer and is equipped with diaphragms and discharge outlets so operated that should a pressure in the discharge side or a partial vacuum on the inlet side occur, the valve would open with a free-fall to the drain. These valves can be set to operate at any desired differential in pressure and will function should these differential limits be exceeded. Such a valve installed in the main water line to a sewage plant would afford adequate protection and could be used in lieu of an open tank and repumping the water. These valves are, however, somewhat expensive.

At one pumping station visited, the water used for seals in pumps and meters was discharged into an open tank from the public water system and was re-pumped for use in the plant thus affording a complete separation between sewage and water. In the same plant, there were some connections for flushing sewage lines and removing deposited sediment. These flushing connections were for hoses and the hoses were provided to connect the water piping to the sewage lines. A sign was conspicuously posted in this station which read, "Hoses To Be Connected For Flushing Only When Essential And Are To Be Disconnected Immediately After Use. To Be Used Only Under Operator's Supervision. Safety Comes First."

Every possible precaution should be taken to protect the safety of the operators in the plant and the public on a domestic water supply system from such potentially dangerous sources of pollution.

In passing, it is desired to bring to the attention of the Sewage Works

Association the matter of hotel sanitation. The American Water Works Association for a number of years has insisted on certain sanitary precautions in any hotel used for a convention of the Association. Several other organizations adopted the same provisions. It is suggested that the Sewage Works Association give some thought to this matter as concerted action on the part of numerous organizations will be effective in rectifying serious health hazards which now exist in many hotels.

In making the examination of the hotels, a standard form was used to facilitate the work and assure complete inspection. This form listed the various pieces of equipment and piping layouts to be examined. Appended to this paper is a proposed form to be used in examining sewage plants for cross connections. This form, while not complete or detailed, may be of some assistance to operators in following the suggestions outlined in this paper.

CROSS CONNECTIONS IN SEWAGE PLANTS

Location of Plant.................................. Type of Treatment.......................

Capacity... Population Served.......................

Sources of Water Supply........................ Date of Survey..............................

WATER CONNECTIONS

Incoming Sewage

Meters.................................... Bar Racks...................... Screens.......................

Mechanical Cleaners.............. Sprays........................... Hose...........................

Grinders.................................. Shredders....................... Flushing.....................

Pumps.................................... Sand Removal............... Flush Tanks.............

Sedimentation

Clarifiers............... Sprays............... Skimmers............ Grease Pumps............

Sedimentation Tanks.......... Coagulation Tanks.......... Mixing Tanks........

Chemical Feeders.......... Sludge Lines.......... Sludge Pumps.......... Hoses........

Digestion

Digester Water Seal......... Heating Coil Makeup......... Sludge Pump.........

Sludge Lines...................... Seeding Pump...................... Hoses......................

Miscellaneous

Air Compressors.................. Laboratory................. Wash Rooms.................

Showers............ Toilets............ Drinking Fountains............ Filters............

Pumps (all types)............ Chlorinators............ Wash-down Hoses............

Summary of Connections Found:

Work Done:

Inspector..

CORROSION OF IRON BY SULFIDES

By RICHARD POMEROY*

The corrosion of iron by septic sewage, sludge, and waters containing sulfides has generally been looked upon as a phenomenon of infrequent occurrence and of little practical importance. Several examples of this sort of action have recently come to light and have made it evident that the problem is serious enough to warrant more attention than it has previously received. The present paper does not attempt a complete survey of this subject, but is prepared in the hope that the presentation of a few typical cases may lead to a better understanding of the behavior of iron in such situations. Descriptions of the selected examples will be followed by a brief discussion of the principles and comments as to remedial measures.

*Of Montgomery & Pomeroy, 117 East Colorado Street, Pasadena, California.

I. OBSERVATIONS

A. Corrosion by Waters Containing Sulfides

1. Septic Tanks

Sulfides are usually present in septic tank effluents, and hence iron exposed to such effluents or immersed in septic tanks should show the extent to which iron is attacked by sulfides. That serious corrosion should be expected was shown by observations in four such situations.

The first example is from La Jolla, Calif., where an 8-inch cast-iron pipe was used for an outfall to discharge into the ocean the effluent from a septic tank. Breaking of the pipe by wave action after 13 years of service led to its abandonment. The inside of the pipe was then found to have a heavy coating of black material, varying in thickness from 1½″ at the top to 3½″ at the bottom, so that the diameter of the opening through the pipe was reduced to 3″. (Figure 1.) Samples of the black material (undried) were found to have the following compositions:*

	I	II	III
Total iron	41.6%	43.7%	
Total sulfur	17.4%	14.0%	
Density			2.07 g/cc.
Compounds present:			
Iron oxide	34%		
Ferrous sulfide, FeS	8%		
Iron disulfide, FeS_2	28%		
Free sulfur	0		
Moisture	29%		29%
Organic matter	1%		
Acid insoluble ash	0.1%		

*Free sulfur was tested for by washing a sample with alcohol, ether, and carbon disulfide. Analysis of this material is complicated by the fact that if it is dried it oxidizes rapidly. becoming quite hot. If the material is treated with dilute HCl, a portion dissolves readily. A further fraction dissolves slowly in more concentrated HCl, but a final residue, grey in color, is not attacked even by hot conc. HCl. The dissolving of the material is accompanied by separation of sulfur.

(See Page 32 for continuation of Footnotes.)

The surprising bulk of the material is correlated with the fact that the iron which went into its composition originally occupied a volume only one-ninth as great as the volume of the product. In other words, as the iron is corroded there is a nine fold increase in volume.

In spite of its bulk the material is hard enough so that its removal from a line would be difficult. Relatively high velocities of sewage flow did not suffice to keep the pipe clean, for the material had collected just as readily where the pipe was laid on a slope of 8% as where it was nearly level.

The metal of the pipe appeared to be very near its original thickness of 0.50″, but observation of the fractured surfaces, as shown in Figure 1, revealed a zone of darkening which had penetrated the metal to a depth varying from 0.06″ to 0.32″, averaging nearly a quarter of an inch. The material in this darkened zone had little of the original strength of the iron. This phenomenon, which is known as "graphitization," will be discussed more fully in a subsequent section.

From a consideration of the factors which control sulfide generation, it is believed that the sulfide concentration in the sewage from this tank was usually between 2 and 10 p.p.m. A single test at noon on Sept. 26 showed 4 p.p.m., and a pH of 6.9.

The exposure of the pipe to sea water on the outside had led to spotted corrosion, mostly of the "graphitization" type, so that the ability of the pipe to withstand mechanical stresses had been greatly reduced. Although the failure of the pipe had been laid to ocean storms, it is evident from the foregoing facts that a major share of the blame should be laid to corrosion. It is likely that this conclusion may apply to others of the many ocean outfalls along the Pacific Coast which have failed long before the expiration of their anticipated lives.

Figure 2 shows a 4″ cast-iron pipe which had hung for six years in a vertical position in a septic tank at San Gabriel, Calif. Holes were eaten through the pipe in places, and the shell of graphitized iron could be broken with the fingers. The deposit on the inside of this piece was about ⅜″ thick, but the pipe had been cleaned a few months before, so that this probably does not represent six years' accumulation. On the outside of the pipe there was a thinner rather hard deposit of nearly pure corrosion product. Beneath this the pipe was smooth and looked like a piece of new cast iron but it could be cut with a knife.

Beckwith (1) has published a photograph of another section of pipe from this same tank.

The horizontal run of pipe carrying the effluent from this septic tank was heavily coated on the inside with a deposit of sludge and iron sulfides. The attempt to clean this section before the pipe was removed had only resulted in cutting of an oblong opening through the deposit, with most

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The insoluble residue, after extraction with CS_2, was dissolved in aqua regia, and was found to contain iron and sulfur in the ratio Fe : 2.12 S. It is evident that iron disulfide (pyrite or marcasite) is present. (The excess sulfur may be due to incomplete solution of residual sulfur by CS_2).

It is assumed that the slowly soluble fraction was disulfide in a finely-divided, reactive state. The excess of iron over sulfur in the whole material shows that not all iron is present as sulfide. It is assumed that oxide is also present, but the composition of the oxide is not known.

The exact proportions of the sulfides and oxide of iron are not known. The above result was calculated on the assumption that all free sulfur separating in the HCl treatment was due to disulfide.

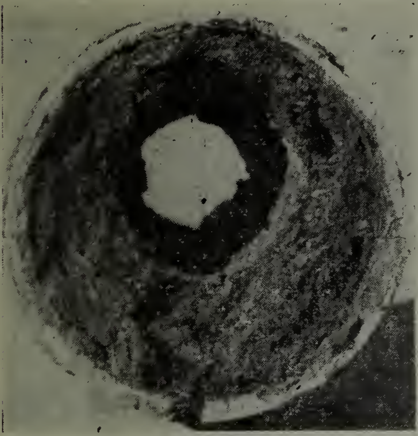

FIGURE 1
Eight-inch cast iron pipe outfall from septic tank at La Jolla after 13 years of service, showing accumulation of corrosion product and graphitic penetration of the metal.

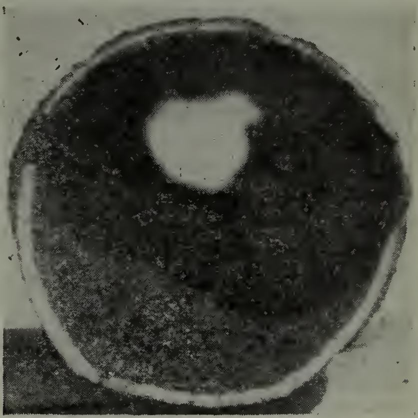

FIGURE 2
Four-inch cast iron pipe which had hung in septic tank for six years, showing penetration of the metal by "Graphitization."

FIGURE 3
Four-inch cast iron effluent pipe from septic tank in Montecito after 4½ years of service.

FIGURE 4
Corrosion of welded steel pipe from sulphide action of oil field waste water.

of the cake remaining in place. As in the example from La Jolla, it is evident that the corrosion product occupied a volume many times as great as the volume of iron consumed.

A single test of the sewage in the septic tank showed 9 p.p.m. of sulfides and a pH of 6.0.

Figure 3 shows a cast iron pipe which carried sewage from a septic tank on the estate of A———— in Montecito, Calif. This pipe was examined after it had been exposed to the weather for several months, during which time the sulfides of iron had changed to hydrated ferric oxide, sulfur, and sulfate. Analysis of the material then found in the pipe showed the following composition:

Acid Insoluble Matter	1.60%
Iron Oxide (Fe_2O_3)	62.00%
Calcium and Magnesium Oxides	0.85%
Free Sulfur (S)	17.77%
Sulfate Sulfur (SO_3)	5.22%
Loss on Ignition (Less free sulfur)	12.56%

It is estimated that the original cake in the pipe (less moisture) was at least 90% corrosion product.

A test of the sewage in this tank showed 60 p.p.m. of sulfides and a pH value of 6.9.

2. Sewage in Treatment Plants

Septic sewage is found not only in septic tanks, but also in many sewage collecting systems. If the corrosion of iron by sulfides is a general phenomenon, we should expect to observe sulfide corrosion in the case of submerged structures in treatment plants where the sewage arrives in a septic condition. The severity of attack will increase as the sulfide concentration increases, and will be more severe at low than at high pH values.

An example is afforded by the treatment plant of Salinas, Calif. After 12 years of service the sludge collecting mechanism in the bottom of primary clarifier is rather deeply corroded, although many more years of service may be expected before actual failure occurs. In contrast to this, the mechanisms in the final clarifiers following the activated sludge process show only slight superficial attack. It is known that sulfides have been present in the raw sewage, though information is not available as to actual concentrations.

Over a seven-year period from 1931 to 1938 the sewage at another treatment plant contained an average of 0.65 p.p.m. of dissolved sulfides and had an average pH of 7.2. Some sulfide attack of iron structures occurred even with this low sulfide content. Cast iron surfaces were not seriously attacked, yet a coating containing sulfides built up to a thickness ¼″ in the seven year period. With 2″ wrought-iron pipe the results were more serious, in part because the wrought iron is attacked more rapidly than cast iron and in part because in pipe of this size less accumulation of corrosion product can be tolerated than in large-size cast-iron pipe. In three years of service section of 2″ pipe developed a coating of ¼″ to ½″ thick, so that replacements were required because of impaired capacity.

Sulfide corrosion of submerged iron structures has been observed in the

FIGURE 5
Remains of impeller of cast iron pump after less than year of service. The water which was pumped contained both dissolved sulfides and dissolved oxygen.

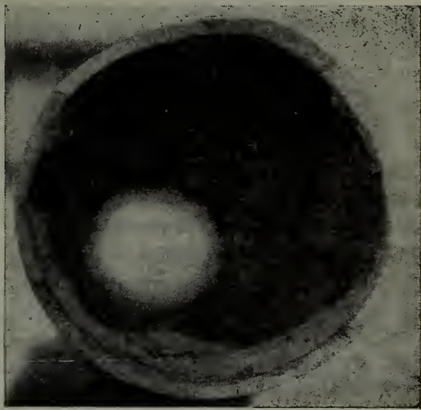

FIGURE 6
Influent pipe to septic tank in Montecito after seven years of service, showing graphitization of the metal, especially at the bottom and left side.

sewerage system of the City of Los Angeles, and the phenomenon is doubtless familiar to many operators and engineers. The two foregoing examples are merely selected as illustrative.

3. Sludge Digestion Tanks

Sludge digestion tanks are also a source of sulfides, in greater or less degree depending upon the relative concentrations of sulfate and of iron in the sewage. There are four digestion tanks in California in which corrosion difficulties have been observed. The most notable case, which is at the Terminal Island plant of the City of Los Angeles, has been described by Mr. Parkes (2). The sewage which is treated at that plant contains at times as much as 25% sea water. No tests are reported for sulfides in the digester, but the high sulfate content of sewage due to the presence of sea water would be expected to produce higher sulfide concentrations than in ordinary situations. The metal structures in the tank were chiefly steel or wrought iron. In 15 months manhole steps were nearly cut through by corrosion. Leaks developed in the 2″ iron pipe heating coils, and other structures showed similar attack. Mr. Parkes made electrical tests which clearly showed that electrolysis was a factor. However, this does not preclude the possibility that sulfides may also have been an essential factor.

In Huntington Beach, wrought iron heating coils in the digester developed leaks after a year of service. A recent test for dissolved sulfides showed 12 p.p.m., but this cannot be relied upon as an indication of average conditions. During the first year of use of this tank, before the digestion process had become stabilized, it is likely that sulfide concentrations were higher and that the pH was lower than during normal digestion.

In Newport Beach, Calif., where the sewage contains much sea water, and where the sludge therefore probably contains high sulfide concentrations, the blow-off line in the bottom of an Imhoff tank was attacked. The line was of cast iron with flanges held together by steel bolts. The bolts failed due to corrosion. The cast iron was also corroded, but not so seriously as the bolts.

The sewage at Laguna Beach, Calif., is normal domestic sewage. Three dissolved sulfide tests in the digester during 1940 showed concentrations from 7 to 9 p.p.m. The heating coils were of cast iron, but with wrought iron pipes entering and leaving the tank. Within four years the wrought iron pipe developed leaks. The cast iron was also corroded, but not seriously.

The digestion system of the Los Angeles County Sanitation Districts provides a case where sulfide concentrations were known to be low. The average dissolved sulfide concentration was estimated to be 0.3 p.p.m. No significant corrosion was noted after nine years of service.

There are doubtless many sludge digestion tanks in which sulfide concentrations are high, and in which corrosion is in active progress. The fact that so few cases have been reported may be explained in part by the fact that most digestion tanks with complicated iron structures are less than ten years old, and in part by the fact that in many situations there is little opportunity to observe the progress of corrosion until actual failures occur.

4. Other Sulfurous Liquids

Sewage and sludge are not the only liquids which may contain dissolved sulfides. Oil-field waste waters sometimes develop sulfides, and unless the pH is quite high serious corrosion may result. A typical case is a welded steel pipe line 4″ in diameter and 3800 ft. long, located in Signal Hill, Calif. The water carried by the pipe shows about 10 p.p.m. of dissolved sulfides and a pH of 7.4. After 10-12 years of service the pipe is developing frequent leaks due to internal corrosion, particularly at the welded joints. Repairs are costing $250 per year.

Figure 4 shows another example of sulfide corrosion by oil-field waste water.

A pump used during the construction of a tunnel handled spring water with sulfide concentrations ranging from 0 to 12 p.p.m., and with a pH of 7.4 Dissolved oxygen was also present. The cast iron impeller fell to pieces in less than a year. (Figure 5.) The high velocities had scoured away the corrosion product and part of the graphitized iron, leading to more rapid attack than occurred on adjacent wrought iron pipes where velocities were lower.

Stumper reports that cast iron pipe carrying water with 0.5 p.p.m. of hydrogen sulfide failed within three years, (3).

B. Corrosion by Soils Containing Sulfides

Sulfides are also produced in soils rich in sulfates and organic matter and devoid of oxygen. It is now recognized that sulfide corrosion of pipe lines in such soils is widespread and serious. This phenomenon is frequently referred to as "bacterial" corrosion, since bacteria are responsible for the production of sulfides. Hadley (4) reports extensive investigations of petroleum pipe lines in three eastern states, with results showing that sixty per cent of the lines are in need of protection against sulfide corrosion. He also presents

data showing that sulfide corrosion proceeds at an accelerating rate, in contrast to rusting which progresses more slowly as the oxide layers increase in thickness.

C. Corrosion by Gases Containing Sulfides

1. Rusting

Unfortunately sulfides are not confined to the liquid where they are produced, but may escape as hydrogen sulfide gas. The rusting of iron in pump stations, manholes, and other structures in proximity to septic sewage is too well-known to require further elaboration here. It is not known in these cases whether the hydrogen sulfide is oxidized to sulfuric acid on the iron surfaces, as occurs in the sulfide corrosion of concrete, or whether ferrous sulfide is first formed and then oxidized by the air to iron oxide.

2. Corrosion With Production of Iron Sulfides

a. Hydrogen sulfide from septic tanks.

It has now been found that there are many conditions under which the exposure of iron to hydrogen sulfide gas leads to the accumulation of iron sulfides. Figure 6 shows the influent pipe to the septic tank on the estate of A———— in Montecito, Calif., after seven years of service. Graphitization of the cast iron had progressed half way through the pipe in places. The pipe carried strictly fresh sewage, but sulfide corrosion product had accumulated, so it is concluded that hydrogen sulfide gas from the septic tank had been responsible. The attack was just as severe seven feet from the tank as adjacent to it.

A 4″ cast iron pipe leading to a septic tank was installed in 1919 on the estate of M———— in Montecito, Calif. In 1937 a stoppage occurred near the septic tank. A local plumber, who serviced the installation, reported a hard black material on the inside of the pipe. An inspection was made in September, 1940. At this time the top of the pipe was easily punctured with a pick. The bottom was fairly clean, but the top had a coating ¼″ to ½″ in thickness, consisting, apparently, of a mixture of iron sulfide and rust. The graphitization had penertated to an average depth of about 0.03″, but in spots the entire 0.16″ of metal had been affected. No data could be obtained on the condition of the metal at the bottom of the pipe. The pipe was carrying fresh sewage, which, as would be expected, was found to be devoid of sulfides, so it seems likely that hydrogen sulfide gas was responsible. A test of the sewage in the tank showed 4 p.p.m. of dissolved sulfides and a pH of 7.5.

b. Corrosion of plumbing by hydrogen sulfide from sewers.

Hydrogen sulfide may come not only from septic tanks, but also from sewers, especially in warm climates in southwestern United States. House connections and plumbing may be damaged by gas from such sewers.

In several buildings in Tucson, Arizona, severe sulfide corrosion of the plumbing has been reported. An example of this is a hotel in which cast iron plumbing was installed at the time of construction in 1908. Leaks began to appear after about 15 years. The attack has been most severe along the top of horizontal runs of pipe. Since a hole in the top of a horizontal run does not necessarily result in serious leakage, much of the pipe remained in

place until the corrosion was far advanced, but replacement of several lengths through the years has been required. An inspection in December, 1940, showed that the three 4″ connections from the basement to the sewer in the street were eaten through along the top, and were nearly plugged with sludge and corrosion product, so that immediate replacement was necessary. The attack is most severe in the basement, but is observed even on the second floor. There is a photograph of a section of 2″ cast-iron pipe taken from the second floor, showing graphitic penetration which has produced a series of holes along the top. The bottom of the pipe is intact. The accumulation in the pipe contains ferrous sulfide and sulfur, proving that sulfides were a factor in the corrosion.

Sulfide corrosion of plumbing has been observed in Los Angeles, and cases of corrosion in which sulfides probably played a part have been reported from San Diego and Santa Barbara. There is no doubt that the list of examples of corrosion of this type could be extended almost indefinitely if sufficient time were available for investigation. It is also quite certain that sulfide corrosion has often been an important factor in stoppages in plumbing systems. The significance of corrosion in such stoppages has probably been overlooked because the graphitic nature of the attack of cast iron may leave the surface nearly unaffected, and because plumbers and others having an opportunity to observe such corrosion have not been on the lookout for it.

In view of the relatively large investment in house plumbing as compared to sewerage systems, it is likely that from an economic standpoint this corrosion of plumbing and house connections is the most serious form of damage resulting from sulfides in sewers. Where sulfides are a problem the sanitary engineer and chemist should not confine their attention within the limits of their sewerage system, but should give thought to the effect of sewer gases on the private property of the citizens.

II. DISCUSSION OF PRINCIPLES

It is possible that iron may be corroded by sulfides with evolution of hydrogen, according to the reaction

$$Fe + H_2S \rightarrow FeS + H_2$$

It does not seem likely, however, that this reaction accounts for any considerable attack of iron, except when the pH is quite low. Laboratory experiments by the author, in which iron was immersed in sludge or sulfide solutions under strictly anaerobic conditions, showed corrosion rates too low to be of practical importance. (5).

It is probable that corrosion as serious as that represented by the examples given in this paper is possible only when an oxidizing (depolarizing) agent enters into the reaction. If oxygen plays this role, the reatcion may be written

$$Fe + O + H_2S \rightarrow FeS + H_2O$$

A consideration of the circumstances under which the reported instances of corrosion occurred shows that in most cases oxygen may have been present either as air or in solution because of previous exposure of the liquid to air or because of leakage into pumps. The exceptions are the primary clarifier at Salinas and the sludge digestion tanks.

Unfortunately it is not necessary for the oxygen or other oxidizing agent to be present at the same location as the sulfide. If two pieces of iron are

exposed respectively to waters containing sulfides and oxygen, and if there is a complete metallic and electrolytic circuit between them, electrolysis will take place with corrosion of the iron which is exposed to sulfides. It is probable that this is the commonest form electrolytic corrosion.

The conditions for electrolysis are fulfilled in the case of the clarifier at Salinas, in the digestion tanks, in pipe lines corroded by soils, and under various other circumstances. It is only on the inside of pipe lines, or in the cases of isolated pieces of iron completely immersed in septic liquids, that conditions are such as to render improbable the action of extensive electrolytic currents.

Thus in all of the reported examples of sulfide corrosion we have the possibility of either the simultaneous presence of oxygen and sulfides, or electrolysis, or both. It is not yet established with certainty that iron is not appreciably corroded by sufides when neither of these conditions is fulfilled, but this conclusion is indicated by the experiments cited (5), and by the observation of Parkes (2) that some manhole steps in the digester were intact. Such a conclusion is of practical significance. If true, it may indicate, for example, that sulfides are not a danger to iron or steel force mains carrying septic sewage, provided the pump does not suck air, and that construction of digestion tanks of steel is a safe procedure. It may be found that ocean outfalls such as that at La Jolla are not affected by sulfide corrosion out where the pipe is entirely filled and where the sewage has become strictly anaerobic.*

When cast iron is corroded by sulfides, and by various other agents as well, the penetration is the "graphitic" type. The nature of this change consists in removal of all or part of the iron, leaving behind graphite, carbides and silicides of iron, and other impurities. This is brought about by a small-scale electrolytic process. Evidently the corrosion product is a fair conductor of electricity. The iron is dissolved at the front of the zone of graphitization, while oxygen is reduced at the surface of the corrosion product, or on other metal surfaces in electrical contact with the corroding iron. The pores in the graphitized material are filled with a dilute, slightly acid solution of ferrous salts, as may easily be demonstrated by tests. The ferrous ions diffuse back through the mass until they are precipitated as sulfide or hydroxide, by sulfides or alkaline substances in the water.

The mechanism of formation of iron disulfide, which involves further oxidation, has not been explored.

III. PRACTICAL CONSIDERATIONS

From the examples given it is evident that the corrosion of iron by septic sewage is not an exceptional occurrence, nor is it a matter of little economic significance. The question of greatest practical importance, of course, is what to do about it.

One method which suggests itself is the use of protective coatings. In

*Kuhr (6) believes that the iron may be oxidized by sulfate through the action of bacteria. There does not appear to be sufficient evidence to warrant the conclusion that the reaction necessarily follows the mechanism which Kuhr proposes. In view of the experiments by the author (5) in which high concentrations of sulfate were added to sludge without inducing significant corrosion of iron, it does not seem likely that sulfate is an effective oxidizing or depolarizing agent for such corrosion. Even under the catalysing influence of bacteria, sulfates produce oxidation-reduction potentials which are not much higher than the potentials at which hydrogen is discharged from neutral solutions.

In this connection, see also Bunkers (7).

the case of pipe lines laid in the soil, such coatings are valuable, not only because they prevent contact of the pipe with sulfides in the soil, but also because they keep oxygen from the pipe where the soil is aerated, and thus prevent electrolytic currents. But for structures exposed to septic sewage or sludge it is difficult to apply a coating thick enough and impervious enough to be effective for very long. If there is a chance for electrolysis, a coating with a few imperfections may be worse than none at all, for it may concentrate the current and hence the attack, and may lead to more serious damage than if the action is distributed over a wide area. In many cases, as on the inside of pipes, periodic replacement of the coating is impractical. All-in-all, reliance upon protective coatings is seldom a satisfactory solution for the problem of corrosion by septic sewage.

Often the best procedure is to eliminate sulfides from the sewage. Several methods are now available to accomplish this; discussion of these techniques is beyond the scope of this paper.

Attention should be given to minimizing the iron structures in septic tanks and digesters. Where corrosion of the necessary structures occurs, it may be possible to make them easily replacable, as has been done in the case of the heating coils at Laguna Beach and at Huntington Beach, Calif.

Cathodic protection has been used in the digestion tank at Terminal Island, (2). Beckwith (1) questions the effectiveness of this method in the case of bacterial sulfide corrosion. That it has been successful in protection of pipe lines cannot be doubted, and it is certain that many of the lines where it has been employed were subject to sulfide corrosion. The digester at Terminal Island has recently been inspected, and it is evident that corrosion has at least been greatly retarded.

Another method which may be used in the case of digestion tanks is to insulate the internal structures from metallic contact with re-inforcing steel or other structures about the plant, and thus prevent electrolytic currents. This principle has been applied in one recent installation.

From what has been said previously, it is evident that pumps handling septic sewage should be designed to prevent the sucking of any air.

Ocean outfalls for the smaller sewerage systems still offer a problem. These outfalls suffer not only from sulfide corrosion, but also from sea water corrosion and mechanical damage by the ocean. This combination of difficulties may often indicate the desirability of sewage purification to render unnecessary a long ocean outfall, or the collection of sewage from larger areas to reduce the number of such outfalls. Where outfalls are required, the removal of sulfides from the sewage may sometimes be an economical method to lengthen their lives.

In the case of pipes carrying sewage, and especially house connections to the sewer, it is evidently desirable, where possible, to turn to more resistant materials. The common vitrified clay pipe is resistant to corrosion, although the cement joints may sometimes suffer attack by the sulfuric acid formed by bacterial oxidation of hydrogen sulfide. This was illustrated in the effluent pipe from the septic tank on the estate of A——————————— in Montecito. The original cast iron pipe (Fig. 3) was replaced by clay pipe, but within a year the joints of the line, which was not covered, showed considerable leakage. This example may be exceptional, but it is likely that

other such cases have escaped notice because the pipe was buried. Clay pipe with concrete joints also has the more serious disadvantage that the joints are seldom absolutely tight. Exfiltration of moisture through the joints, and in fact through the pipe itself, attracts tree roots which may gain entrance to the pipe. This, indeed, has been the chief reason for resort to iron pipe.

A new type of clay pipe, which is now being extensively used in southwestern United States, seem to offer an answer to this phase of sulfide corrosion. The pipe is of an impervious clay. Joints are made in separate collars which extend over the butt ends of connecting pipes, and are sealed with a hot-poured compound. Pressure tests show practically no leakage.

Abstract

Serious corrosion often occurs when iron is exposed to sewage or sludge containing considerable amounts of dissolved sulfides, or to hydrogen sulfide gas. The corrosion product is remarkably voluminous, yet hard enough to remain in place, and frequently to cause stoppages in pipes.

It seems likely that occurrence of such corrosion requires the presence of oxygen as well as sulfides, but the oxygen may function remotely by means of electrolysis.

Remedial measures are discussed.

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DISCUSSION OF DR. POMEROY'S PAPER ON SULFIDE CORROSION OF IRON

By **HARVEY F. LUDWIG**

In the case of cast iron water pipe of Imperial, California, mentioned by Mr. Ramseier, the corrosion may have resulted from a mechanism termed "contact exchange" by colloid chemists. This phenomenon has been demonstrated by suspending an iron nail in a suspension of colloidal clay containing exchangeable hydrogen (i.e., the clay particles have some H^+ counter ions). As the clay particles contact the nail an ionic exchange occurs in which Fe^{+++} ions of the nail replace H^+ ions because the former are more strongly adsorbed. Eventually the iron nail will disappear as it is completely converted to hydrogen. The same reaction might account for the external corrosion of pipes when laid in acid soils.

DISCUSSION OF DR. POMEROY'S PAPER ON SULFIDE CORROSION OF IRON

By R. E. RAMSEIER

I've run into two examples of iron corrosion that I couldn't explain and maybe this is the answer. In 1940 the sewerage system at Decoto, California, was completed and the Masonic Home was abandoning their septic tanks. They wished to use an 8″ cast iron line that had been layed in 1930, and had been used for septic tank effluent. When they uncovered this pipe it looked like new cast iron pipe, but the inspector hit it with a screw driver and pushed a hole through it. The pipe was so full of corroded material that there was only a two inch space for the sewage to flow. I don't know just how strong the sulfide was but by a practical test it was about fifty feet.

Another bit of cast iron corrosion that may be attributed to sulfide was the disintegration of a cast iron water pipe in Imperial, California. The water is very high in sulfates (about 350 ppm) and although this pipe was carrying water there may have been sulfides in the soil around it. The pipe material left was light and could be easily cut with a pen knife.

I tried Dr. Pomeroy's flame test on a sample of the pipe from the Masonic Home and the corroded portion is high in sulfur.

SULFIDE CONTROL IN A SEWERAGE SYSTEM

By FRED D. BOWLUS

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Although a considerable amount of sewage testing was necessary in 1932 at the time the Los Angeles County Sanitation Districts first instituted the chlorination of its sewerage system, comprehensive studies of sulphide control have only been in progress during the past two years. Aside from the innumerable tests of sewage made at representative sampling points in the various districts, many tests were made of the air within the sewers, manholes and pumping plants. Physical examinations of the sewer structures themselves were made by men travelling through several miles of the larger conduits.

Digestion of the data assembled has led to the relocation of chlorine stations and to the revision of the chlorine schedules. While the Joint Disposal Plant was being operated on the activated sludge process, reductions of sulphide by chlorine application, materially aided in producing a better sewage effluent. With the advent, in 1937, of ocean disposal through the new tunnel and ocean outfall the plant has been run on the plain sedimentation process and sulphide control was therefore of less importance so far as sewage treatment was concerned.

From the first addition of chlorine to the system, odor nuisance complaints were eliminated. Therefore, the problem now is largely one of adequately protecting the large investment in the sewerage system conduits, structures and pumping plants.

Sewage flow at the Joint Disposal Plant has increased five fold during the past ten years, but only 50% more chlorine has been added. As a result of more efficient application less sulphides are now found than when the chlorination schedules were first arranged.

The chlorination program of the County Sanitation Districts had originally been based on the assumption that prechlorination to a residual was the best method of sulphide control. Recent tests, however, have revealed that in most cases complete reduction of only the dissolved sulphides is necessary. These changes in feed, having been made, effected a savings of several thousand dollars per annum. After all, the source of the destructive agency, hydrogen sulphide in sewage, is the dissolved sulphide, not the inert sulphide.

Recent tests at the chlorine stations revealed that the average ratio of chlorine used to sulfides destroyed was 5.3 to 1, whereas the theoretical reaction should only require 2.2 pounds of chlorine to one of dissolved sulfides.

Since more than half of the applied chlorine was being wasted by uniting with other harmless compounds in the sewage, research was directed to other means of sulfide reduction. Considerable information was gathered from the application of various metallic salts to sewage flowing in the sewers and through long pressure pipe lines. Various compounds of iron, zinc and copper have been used.

Gardena Sewer

A two mile trunk collecting domestic sewage from the City of Gardena was used for some of the tests. Pipe diameters are from 15″ to 24″ on flat grades averaging 0.10%. Transit time of sewage was about three hours. The daily peak flow over a five hour period averaged from .30 to .35 mgd and carried at least 2 ppm of dissolved sulfides during the summer months. In April, 1939 a ferric chloride solution was fed into the sewage for a period of four hours at the rate of 10.2 pounds of iron per day (4 ppm). Sewage samples taken every twenty minutes one and two miles below were analyzed for both dissolved and total sulfides using the Pomeroy method.

Only slight sulfide reductions were noticeable at either point of the test even though the sewage carried only 1 ppm of dissolved sulfides at the lower station prior to the iron dosage. Later a copper sulfate solution was injected at the upper end of the sewer at the rate of 14.4 pounds of copper per day (6 ppm). At the midway station both total and dissolved sulfides were eliminated and at the lower station the dissolved sulfides were reduced to 0.2 ppm.

In May, a zinc sulfate solution was fed into the sewer at a rate of 21.5 pounds of zinc per day (8 ppm). At the midway station tests revealed a doubling of the total sulfides and absence of all dissolved sulfides. At the lower station the total sulfides were further increased, but the dissolved sulfides averaged only about 0.2 ppm.

A test was then made near the lower station on this trunk sewer where metal salts were applied to the sewer at one manhole in varying amounts. Sewage was also tested at the next manhole below. The dissolved sulfides in the untreated sewage ran from 0.6 to 1.5 ppm. During one hour tests with ferric chloride at dosages of 12.2 and 29.1 pounds of iron respectively (5.1 and 9.4 ppm) no decrease in dissolved sulfides was found, but when the rate of 45 pounds a day (15.0 ppm) was used the dissolved sulfides were reduced to about 0.4 ppm.

With a similar short contact period further tests were made using a ferrous sulfate solution feeding at the rate of 15.7, 28.2 and 47.0 pounds of iron (6.5, 9.1 and 15.7 ppm) per day. With the highest rate of feed (16 ppm) total sulfides were reduced from 2.2 ppm to 0.7 ppm and the dissolved sulfides from 1.5 to 0.1 ppm. It is significant that the ferrous salts not only converted dissolved sulfides to insoluble iron sulfides but actually caused a destruction of part of the sulfides.

A zinc sulfate solution with 9.5 and 12.5 pounds of zinc per day (3.7 and 5.2 ppm) rate of feed caused a slight increase in the total sulfides, but when fed in sufficient amounts converted all dissolved sulfides to inert sulfides. Mixtures of ferrous and ferric salts were also tried and were found to be more effective than either alone in minimizing dissolved sulfides at the point of application, but in this case also excess treatment does not prevent the reappearance of dissolved sulfides in concentrations up to 1.0 ppm.

The following table shows the theoretical chemical reaction ratios between a few treating agencies and dissolved sulfides.

METAL SALTS	RATIO
Chlorine (Cl_2)	2.21 to 1
Ferric Chloride ($Fe\,Cl_3$)	1.16 to 1
Ferrous Sulfate ($Fe\,SO_4$)	1.74 to 1
Copper Sulfate ($Cu\,SO_4$)	1.98 to 1
Zinc Sulfate ($Zn\,SO_4$)	2.04 to 1
Zinc Chloride ($Zn\,Cl_2$)	2.04 to 1

The District's tests show that zinc and copper salts eliminate dissolved sulfides more completely than the iron salts. The latter in sufficient quantity will almost completely eliminate the dissolved sulfides in the sewage, but two miles below they re-generate to about 1.0 ppm. Copper and zinc dosages practically eliminated the dissolved sulfides from the sewer for its entire length.

During the fall of 1939 ferrous sulfate was fed into this same sewer continuously day and night for a period of nearly two months, excepting when it was shut off in order to sample the sewage without the iron for a few hours.

Tests made two miles below, over the same two hour period, showed some reduction in dissolved sulfides. Even though the rate of iron application was increased from 3.9 to 46.4 ppm of sewage, no test showed complete destruction of dissolved sulfides. With 32.4 ppm the minimum was 0.5 ppm of dissolved sulfides in one instance. Most tests showed more.

Sulfide control of the Gardena trunk was not only desirous for protection of the concrete conduit itself, but to reduce odors and prevent concrete deterioration at the Gardena sewage pumping plant. Hydrogen sulfide is readily released as the sewage drops from the influent line into the wet well of these plants. Tests of the air in several pumping plants and in manholes where vertical drops occur show that sewage carrying dissolved sulfides in amount of only 0.2 to 0.5 ppm will cause 10 to 20 ppm of hydrogen sulfides to be found in the air in these confined places. For complete protection of these structures, therefore, the dissolved sulfides in the sewage should be almost entirely eliminated.

A trial run will be made on the Gardena Trunk sewer using zinc sulfate as a control agency during the summer of 1941.

North Long Beach Force Main

In North Long Beach, local sewage is pumped through a 4300 foot force main consisting of a 21″ pipe to a junction with the District's Joint Outfall. At this point there is a drop of ten feet causing considerable turbulence. A test in the winter showed that sewage carrying 3.0 ppm of dissolved sulfides gave a concentration of 60 ppm of hydrogen sulfide in the manhole. Dissolved sulfides in the sewage rise to 10 ppm in the summer time at this structure. Rapid disintegration of the concrete had started when a chlorinator was installed at the pump house. The maximum sewage flow of 1.5 mgd also carries the highest dissolved sulfide. During this period the transit time through the force main is 1¼ hours.

Tests show that the chlorine-dissolved sulfide reduction ratio was between 4 and 5. In March, 1940 a test was made with varying amounts of zinc sulfate applied to the sewage at the pump house. The zinc-dissolved sulfide reduction ratio was about 2. In contrast to the Gardena sewer tests the total sulfides remained about the same with or without zinc dosage, but the dissolved sulfide was converted into inert zinc sulfide. In this case in spite of the fact that zinc is more effective than in the Gardena trunk, chlorine probably remains the more economical of the chemicals because of a more favorable cost. In passing it may be stated that treatment of the influent sewage at the pumping plant has also controlled a serious odor problem in the community.

San Gabriel Plant Force Main

East of Monterey Park the sewage from San Gabriel collects at a pumping plant and is pumped through a 12″ C.I. force main a distance of 6800 feet to a pumping plant in Monterey Park, with the usual drop and release of hydrogen sulfide gas. Odor complaints from the surrounding neighborhood were serious. On account of the rapid increase in connections the maximum flow has risen from 0.3 to 0.5 mgd. Transit time of sewage in the force main now varies from 2½ to 10 hours. Peak of the dissolved sulfides was 4.0 ppm last summer at the outlet end of the pipe. This gave a concentration of 20 to 30 ppm of hydrogen sulfide gas in the air of the wet well at the pumping plant. It was decided to use zinc sulfate for sulfide control in this case instead of purchasing a new chlorinator.

Zinc sulfate solution is being delivered in 50 gallon drums at a specific gravity of about 40° Be. Experience gained in tests with solutions of this metallic salt pointed to the difficulties with trying to feed less than 100 CC per minute. Crystallization of the solution and clogging of smaller orifices occurred. At the San Gabriel plant a 20 gallon crock was mounted on the sewage influent line and the solution fed through a glass nozzle connected by a hose. The glass tube was drawn out over a flame to the desired diameter. The crock is filled twice daily at the beginning and end of each eight hour shift of the plant operator, the zinc feed also being changed at these times. By feeding the solution at 100 CC per minute, the required amount of zinc for full sulfide control at Monterey Park pumping plant called for a dilution to 20° Be for the day feed and 15° Be for the night feed. At each refill the operator pours the concentrated zinc sulfate solution into a jar and adds sufficient water to bring the specific gravity to the desired point as indicated by a hydrometer. As the level of the solution lowers in the crock the orifice discharges

at a lower rate, from 10 to 20% before the crock is again refilled. This is of some economical advantage since the zinc demand of the sewage is greatest at the time when the refill is made. This sulfide control measure has eliminated all the hydrogen sulfide odors from the Monterey Park plant as checked by careful tests. Seventeen pounds of zinc are being applied daily.

Artesia Plant Force Main

At the Artesia pumping plant a 6500 foot 10″ cast iron line is used as a pressure main to transmit sewage from that town to the District's trunk sewers. A peak flow of .10 mgd gives the shortest detention time of about five hours. Dissolved sulfides rise to over 5 ppm at the outlet end during the summer months. Two tests were run dosing the influent sewage at the pumping plant at a rate of 10 and 20 pounds of zinc per day. Only with the greater amount were all dissolved sulfides removed.

Sulfide Control in Sewers

Several other tests have been made by the Districts in the application of zinc sulfate to sewers carrying high concentrations of sulfides for general purposes of line protection and odor nuisance abeyance. The Norwalk extension trunk sewer in addition to collecting the domestic sewage of the town of Norwalk takes the waste from several dairies. The largest, milking 500 cows is at the upper end of a local sewer west of town. This sewer is 4.1 miles in length and sulfides mount to 5 or 6 ppm during the peak summer flow of .20 mgd. Dosage with zinc sulfate in two tests indicated that the sulfides may be satisfactorily controlled with metal salts.

The Wadsworth Avenue trunk sewer layed with cement pipe on a flat grade has a peak flow of .70 mgd and carries a maximum of 1.0 to 1.5 ppm of dissolved sulfide during the summer months. A three hour application of zinc sulfate to the upper end of this line showed the dissolved sulfides were entirely removed at a point 1.4 miles below, by dosage at a rate of 21 pounds of zinc per day. The addition of zinc doubled the total sulfides and hence required a zinc dosage about twice as great as would be anticipated on a basis of the original dissolved sulfide content. Simplicity of feeding a zinc solution compared to the cost of a new chlorinator in this case justifies the use of zinc sulfate as a sulfide reduction agent. The same trunk was also dosed for a like period with zinc chloride and the same results obtained.

An interesting experiment was run on trunk sewers in District No. 1 where the combined flow amounts to 20 mgd during the daily period of sulfide peaks. A 750 pound chlorinator is located at the junction of three large trunks on Artesia Street 1.1 miles above the lower end of the District. A smaller chlorinator serves the east branch at Atlantic Avenue 6.2 miles above this junction and another at Compton Station on the middle branch 3.5 miles above the junction. The 1940 scheduled chlorine feed rate for the hours of peak sulfide content was 250 and 600 pounds per day, respectively, at the Compton and Artesia Avenue Stations. Tests at the lower end of the district showed an average dissolved sulfide content of .2 ppm during that period.

Assuming that zinc would cost twice as much per pound as chlorine, a test was run for a period of nearly three hours when zinc with half as many pounds as the chlorine schedule required was fed into the middle branch at a point 1.6 miles above the Compton Chlorine Station. Tests showed the same reduction

of sulfides at the lower end of the District as when chlorine was fed. Simultaneous tests at the Compton and Artesia Avenue Stations showed that all dissolved sulfides were removed at those points as was ordinarily done with the chlorine application. In this case the zinc sulfate solution applied to a flow of less than 2 mgd at a single point protected more of the sewer line at about the same cost as chlorine applied at two points.

Conclusions:

Tests of the Los Angeles County Sanitation Districts during the past two years reveal that use of metal salts may be advantageous under certain circumstances for the control of sulfides in sewerage systems. Because of its low cost iron may be used at a point where high sulfides are to be eliminated, but tests show that complete removal of all dissolved sulfides is impractical and it seems inactive at any great distance below the point of dosing. In contrast with chlorine, which satisfies many demands of a sewage other than the dissolved sulfides, zinc and copper apparently find little else with which to combine, and therefore are more efficiently applied. The tests have clearly demonstrated that zinc may be applied to a small quantity of sewage and yet be available for sulfide control miles below where the flow is many times greater. Use of zinc is particularly adapted to sulfide control in long force mains. It is also the most economical way to correct sulfide control problems where the sewage flow is small, since the first cost of a zinc feeder is so much less than that of a chlorinator. While the transportation cost of servicing the zinc station is greater than a chlorine station, because of the added bulk, this is probaly offset by the cost of a water supply for the latter. The zinc solution may be applied where there is no available water supply. In a metropolitan area the hazards of trucking a zinc solution are much less than chlorine.

Investigations have been made of several other methods of sulfide control, and each was found to have its appropriate place of usefulness. These methods include: Control of pH, ventilation, Scott-Darcey process, ammoniation, control of industrial wastes, aeration, and redesign of the sewerage system.

While this discussion is by no means a complete report on sulfide control, as it presents only a small fraction of the data collected, it is offered as a progress report. Research is being continued by the Los Angeles County Sanitation Districts.

Dr. Richard Pomeroy was research chemist for the Districts until May, 1940, and collaborated extensively on this work.

COOLING OF SEWAGE GAS ENGINES AND WASTE HEAT RECOVERY

By J. H. WALLACE*

The modern sewage disposal plant produces hydrocarbon gases as a by-product of the digestive process. This gas generally contains, among other things, those gases which possess objectionable odors, and it is therefore customary to burn this gas either as fuel or as a gas flare for the purpose of disposing of the gas together with its objectionable odors. Since this disposal of the gas represents a waste of real value, it is becoming increasingly important to engineers to attempt to utilize this waste. The amount of gas varies with the type of plant and with the type of waste received at the plant. There are no very good records as to the average amount of gas produced and probably the best reference is that given by Mr. Walraver of the Springfield Sanitary District who states that the amount of gas developed per 500 persons of population will develop one brake horsepower continuously.

The burning of this gas in an internal combustion engine as a prime move for driving generators, pumps, or air blowers probably represents the most forward step that the industry has taken for a number of years, and it will become increasingly important in the light of present day events. Perhaps it is strange to see any possible connection between the preparedness program and the burning of sludge gas in engines for sewer plants, nevertheless there is a very real connection. First, the defense program now under way is utilizing more than ever the internal combustion engine. This has been brought about particularly by the very bitter lesson learned in Europe that central plants can be easily destroyed whereas outlying plants represented far more security; and second, by the fact that modern war relies entirely upon internal combustion engines for its mobile equipment. At the present time, every engine builder in the United States has his plants filled to capacity; and, it is safe to say that the production capacity in this country for making large bore, heavy-duty engines will be quadrupled due to this program. This will have two direct results on the engine business. First, it will perfect the design and modernize the large bore engine which has been woefully out of date. Second, it will transform the large bore engine from a handmade article to a factory produced product and will permit the builders to have sufficient tools and facilities for mass production. When the preparedness program is over, these tremendous engine producing facilities will be looking for new outlets, and the progressive manufacturers will have in their possession perfected designs and tools to produce at low cost so that, in my opinion, engines will be purchased for less than half the present per horsepower cost. At this price, the industry will not be able to overlook the use of engines as prime movers, particularly where the fuel is free and must be disposed of to prevent the release of noxious gases.

In addition to these economical advantages, the gas engine has the advantage of flexibility which is not possessed by the electric motor. In the case of direct operation of pumps, blowers, etc., the engines can be automatically controlled to vary their speed with the demands of the plant and thus lend themselves to plant flow control.

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Almost any type of engine can be made suitable for operation on sewer gas. In general, there are only three considerations involved, aside from the amount of power required. First is the speed at which the unit is to be operated. This is independent of the fuel and dependent upon the economics of the plant and the engineers balance of first cost against operating costs. Second, a suitable compression ratio for the type of gas to be burned. In general, it may be stated that any engine suitable for burning natural gas will be suitable for sewage-sludge gas. The compression ratio being in the neighborhood of from 6 to 7½ to 1. Third, the BTU value of the gas will determine the maximum brake mean effective pressure obtainable and hence the maximum horsepower available from any given engine.

The fuel problem is the same for all engines and is by far the most important factor in the successful operation of sludge-gas engines. Sludge gases are composed essentially of methane and carbon dioxide, with small amounts of hydrogen, nitrogen, chlorine and hydrogen sulphide. The power giving element in the gas is primarily methane. The carbon dioxide acts as a dilutent. The hydrogen is also a source of power. The nitrogen, chlorine, and hydrogen sulphide are the products that cause most of the trouble. When combustion takes place, water is formed as a product of combustion. The amount of this water depends, to a large extent, upon the type of fuel, with methane giving the highest percentage of water. The amount of water from methane is approximately 1¼ gallons per 10 brake horsepower hours. During combustion, any sulphur or hydrogen sulphide present is burned to sulphur dioxide and then to sulphurous acid and then, due to the presence of moisture, pressure, and temperature, to sulphuric acid. In a like manner, the nitrogen produces nitric acid and chlorine may go to hydro-chloric acid. The presence of these products of combustion may be so serious as to absolutely prevent the successful use of engines in sewage plants unless special precautions are taken. Hydrogen sulphide may, to some extent, be removed by scrubbers, however, the effectiveness of scrubbers drop very rapidly as the concentrations of hydrogen sulphide are reduced, and I do not believe that it is economically feasible to reduce the hydrogen sulphide to below .1%.

To give some idea of the destructiveness possible from sludge gas, I will cite one particular example as typical but by no means isolated. The engine involved was a small, moderate-speed engine designed with a high compression ratio and used with satisfaction for low BTU sludge gases. In this particular case, no analysis of the gas was made as the plant was new when installation was made. At the time it was installed, sufficient gas for operation was not obtainable. During the first month or so, when the engine was operated, butane was used as a fuel. As the plant developed gas, the engine would run upon the sludge gas for an hour or so at a time and then return to butane. As the amount of gas in the plant increased, the operation was transferred entirely to sludge gas. At the end of approximately thirty days of sludge-gas operation, the engine required servicing. Investigation showed that the rings were stuck, the liners as well as the pistons showed considerable wear. The liner wear was approximately .030. The crankshaft journals and throws were badly pitted and etched. The oil, which had been drained twice during this period, was badly sludged, its consistency being almost that of mayonnaise. The action of the acid had even extended so far as to be quite marked on the heavy cast iron timing gears. The damage in all was so great that it

was not considered advisable to operate on sludge gas unless some drastic steps were taken. To the operator, we recommended the installation of a "VAPOR PHASE," high-temperature cooling, System. The operator, having seen his engine, was inclined to be anything but hopeful and agreed to install the equipment on a trial basis only. Attempts were made to repair the engine but appeared to be futile, and because of its importance in this field and because we feel that the "VAPOR PHASE" System would permit operation under even these drastic conditions, we installed a completely new engine and a "VAPOR PHASE" Cooling System. This engine has now been operated for more than 1350 hours and has been inspected three times. The oil continues to remain in excellent condition although it is being drained only every thirty days but appears in excellent condition at the end of the thirty days. The mechanical parts of the engine show no signs of wear or the effect from the sludge gas. I believe the operator will testify that this unit is a most satisfactory piece of equipment at the present time, and incidentally, the plant records show less "down time" on the engine unit than on the parallel-electrical units.

I could cite numerous examples quite as startling as this one but do not believe it necessary to go further at this time except to say, we are operating engines in some oil fields where the gas contains 11% hydrogensulphide.

The question naturally arises as to how the jacket water temperature can have such a profound effect on the engine operation, and the purpose of this paper will be to cover the thermo dynamics involved and to show how the temeratures of the engine jacket water is the most important single factor in the operation of internal combustion engines, particularly where methane or gas having sulphur and similar constituents present is used .

The internal combustion engine is a device for transforming one form of heat energy to another, and like all machines is accompanied by considerable losses which appear primarily as heat. The approximate distribution of heat in the internal combustion engine is as follows:

To brake horsepower	26%
To engine friction	6%
To radiation	6%
To exhaust	34%
To jacket water	28%
	100%

From the above figures it can be seen that approximately ⅓ of the total heat of the fuel must be dissipated from the jackets.

During combustion, flame temperatures are in the neighborhood of 3,000°F. In order to remove this heat, the designers of water-cooled engines have followed conventional practices and circulated water through the engine. The amount of heat removed is, of course, easily measured by the quantity of water and its temperature rise through the engine. The greater the amount of water circulated in any given engine, naturally the lower the total rise. This gave rise to the erroneous belief that more efficient cooling occurred with the rapid circulation of water, hence, the cooler the water could be maintained, the lower the temperatures of the engine parts, and apparently little other thought has been given to the cooling system. However, a glance at the

heat balances as made by such notable observers as Riccardo and Judge show that heat concentrations in the heads are far greater than the heat concentrations in the lower portions of the cylinder. Our work in the realm of cooling has lead us to divide the engine into two temperature zones. First, the high-temperature zone which is essentially comprised of all of the cylinder walls and heads above the upper most position of the top piston ring at the time of ignition, and the low temperature zone which consists of all that portion of the cylinder walls below this upper limit. It has been definitely shown by test and computation that the rate of heat flow in this high-temperature zone is in the order of 50,000 to 150,000 BTU per square foot per hour whereas the rate of heat flow in the low-temperature zone is in the neighborhood of 1000 BTU per square foot per hour. Applying now the well-established practices of water heat transfer, we find that water under the best conditions cannot remove more than 500 BTU per square foot per hour per degree Fahrenheit or assuming a 20°F. rise across the engine, a total heat dissipating capacity of 10,000 BTU per square foot per hour. Since this figure is approximately ten times the rate of heat flow in the low-temperature zone, it is obvious that adequate cooling takes place there and that the metal temperatures in this area approach within 5 or possibly 10°F. of the water temperature. However, the heat flow in the high-temperature zone is from 5 to 15 times the maximum possible water dissipation. Since the heat is removed from the upper portions, some explanation of the phenomenon involved is necessary, and this explanation is found in water's unique ability to absorb a tremendous amount of heat in its change of state from water to steam, better known as the latent heat of evaporation. In other words, a pound of water being raised from 211°F. ot 212°F. absorbs 1 BTU whereas in going from 212°F. water to 212°F. steam, it absorbs 970 BTU or approximately 1000 times as much heat. It is this latent heat that makes possible the cooling of the high-temperature zone. What actually takes place is that film of boiling water surrounds this high-temperature zone. This film, however, is only microscopically thick, as the steam formed is immediately recondensed in the surrounding water. Therefore, it is obvious that the water film temperature on the surface of the high-temperature zone is 212° F. at atmospheric pressure or at the boiling point of the water for any other pressure. Therefore, the metal temperatures in the high-temperature zone must be equal to or greater than this boiling temperature, therefore, we can make the following statements:

1. The metal temperatures in the high-temperature zone are independent of the temperature of the water and of the rate of circulation of the water and are only influenced by the pressure or any other condition effecting the boiling point of the water.

2. The temperature in the low-temperature zone is dependent entirely upon the temperature of the entering water. Therefore, an engine with an entering water temperature of 120°F. and a leaving temperature of 140°F. will have a lower cylinder wall temperature of approximately 125°F. and an upper cylinder wall temperature of approximately 225°F. (These are actual test figures.) Thus giving an overall cylinder wall temperature gradient of 100°F.

Now, suppose that we circulated water at a temperature of 212°F. into the engine. The lower cylinder wall temperature would then be in the

neighborhood of 217°F. and the upper cylinder wall would still be at 225°F. or approximately an 8°F. temperature gradient. (These figures are also test results.) The immediate effect of such a condition as this would be the reduction of cylinder wall taper as well as reduction in metal temperature stress. However, the most important effect is within the cylinder and has to do with the condensation of moisture and its subsequent acid formation where such acid forming materials are present in the fuel.

I pointed out that something in excess of 1 gallon of water per 10 brake horsepower hours is formed during combustion. At the time combustion takes place, this water is in the form of superheated steam and the engine can properly be called a partial pressure steam engine. As the piston descends, the pressure is reduced and as the moisture vapor approaches its dew point, it will be deposited upon the cylinder walls. I quote from a standard physics text book, "When a gas containing moisture vapor comes into contact with a surface which is at or below the dew point of the vapor, water will be deposited upon the surface regardless of the temperature of the gas." Therefore, since the pressure is always above atmosphere, it is obvious that condensation will take place upon the cylinder walls if they are below the dew point temperature which will range between 212°F. and 255°F. This moisture is deposited on the down stroke of the piston and upon the up stroke is rolled into and forced by the rings eventually finding its way to the crankcase. In addition, the acids formed during combustion are hydroscopic in character and are immediately concentrated in the moisture on the cylinder walls, hence, we not only get water in the crankcase but acid as well. It is this water together with the acid that forms sludge, reduces the lubricating value of the oil, and causes the corrosion of the working parts of the engine. It would therefore be clear that where the temperatures can be maintained above the boiling point of water, these conditions will be eliminated and actual results show this to be a fact.

However, the benefits derived from absence of sludge, prevention of corrosion, increased oil life, and almost complete absence of cylinder wear, are only part of the advantages although in the case of sludge gas engine, it spells the difference between success and failure. Other benefits are:

A. Decreased friction between the piston and the cylinder wall brought about by better lubrication, and in large bore engines, this amounts to a net saving of approximately 10% at full load and approximately 18% at half load. These conditions alone not only warrant the use of "VAPOR PHASE" Cooling but make it almost mandatory.

The possible benefits, however, do not stop with the increased mechanical efficiency of the unit, but "VAPOR PHASE" makes possible the economical recovery of very large amounts of waste heat. As pointed out, approximately 26% of the total input heat is available in shaft horsepower, 28% in jacket water, and 34% in exhaust. The use of exhaust heat has long been known but has two very serious draw backs. First, to be economical nearly all heat must be in the form of steam and even the best waste heat boilers can produce only about 2 lbs. of steam per brake horsepower per hour, and further, since they maintain in parts of the exhaust boiler temperatures lower than the dew point, the moisture contained in the exhaust is deposited in the boiler producing poor heat conditions and extremely bad corrosive conditions. Further, such boilers are of necessity large, bulky, and very costly, so

that for practical purposes the 2 lbs. of steam made available is rarely warranted by the cost involved. However, in the average gas engine with water cooled manifolds, we have approximately 4 lbs. of steam in the jacket water alone, and since the jacket water temperature is maintained at or above the boiling point, it is obvious that this heat is available in the form of steam and an exhaust-heat boiler utilizing water at or above its boiling point becomes very small and is not subject to any of the corrosion which exists in the standard waste heat boiler; therefore, it becomes a very simple problem to pick up the balance of the waste heat from the exhaust.

We are now building waste heat recovery systems showing a total heat recovery of around 6 lbs. per brake horsepower per hour, and these plants show an all over thermal efficiency including the shaft horsepower of between 75 and 80%. Further, this waste heat can be delivered in the form of steam between 5 and 25 lbs. pressure; in other words, better than one-half of the total heat value of the input fuel to the engine is available in steam. In other words, approximately twice the shaft horsepower taken out of an engine is available in the form of steam. The use of waste heat in sewer plants is not new, and since most of the heat is utilized for heating the digestive tanks, it is possible in this case to recover considerable of the jacket water heat without the use of this high-temperature system. However, the amount of equipment required to convey the heat into the sludge tanks is very much reduced because of the higher temperature with which it can be handled. It is likewise possible to regulate the heat far better than can be done with the low temperature systems.

In closing, let me point out the salient features of the "VAPOR PHASE" System as applied to the sewer gas engine.

1. Reduces corrosion of engine parts.
2. Reduces oil sludging and increases oil life.
3. Reduces liner wear and ring sticking.
4. Makes available approximately 75% to 80% of the total heat value of the sludge gas, for useful work.

This system has passed beyond the experimental stage and taken its place in the realm of accomplished fact as is attested by several hundred applications in six states and on engines ranging from 10 H.P. to 500 H.P. with bores from 3″ to 16″ and of both the two and four stroke cycle.

LABORATORY FLOCCULATION OF EAST BAY SEWAGE AND THE MECHANISM OF FLOCCULATION IN WATER PURIFICATION AND SEWAGE TREATMENT PRACTICE

By **HARVEY F. LUDWIG** *and* **RUSSELL G. LUDWIG**

This paper is a partial summary of laboratory studies which are in progress in the Sanitary Engineering Laboratories at the University of California in Berkeley, under direction of W. F. Langelier, Professor of Sanitary Engineering. The object of these studies is to interpret, in terms of colloidal chemistry, the fundamental mechanics involved in the rapid clarification of natural waters and sewages through the use of chemicals, prolonged mixing, and sedimentation. The laboratory data here presented is limited to observations made in the treatment of analyzed samples of composited domestic sewage obtained through the kind cooperation of the East Bay Cities Sewage Disposal Survey. The tests were made in batteries of 200 ml jars equipped with slowly revolving stirrers, such as are in common laboratory use. The chemicals used included aluminum sulfate, ferric chloride, various bentonites, sulfuric acid, sodium hydroxide, and lime; and these were used either separately or in combination.

LABORATORY DATA

General Characteristics of the Sewage Samples:

Sixteen composited sewage samples of dry weather flows from eight different sewerage systems in the East Bay area were used for the routine tests of this study. In general, the samples were collected above industrial areas, but in eight of the samples an undetermined quantity of industrial waste was present. The samples were composited in the field, and reached the laboratory in a fresh condition. The approximate average characteristics of the dry weather domestic sewage of the East Bay area are given in Column A, Table I, below; and in Column B are the average data for the 16 samples used in the study.

TABLE I: GENERAL CHARACTERISTICS OF THE SEWAGE SAMPLES

Remarks		*A*	*B*
	5-day B.O.D., 20° C., ppm	300	320
	Oxygen consumed, ppm	150	—
(0.1 ppm residual at 10 min.)	Chlorine demand, ppm	11	—
(Retained on Whatman 40 paper)	Suspended solids	310	340
	Turbidity, ppm	—	310
(% of suspended solids)	Volatile solids, %	71	—
(2 hours retention)	Settleable solids, ml/1	16	—

*From thesis prepared in the College of Engineering of the University of California, in partial fulfillment of the requirements for degrees in Sanitary Engineering.

TABLE I: GENERAL CHARACTERISTICS OF THE SEWAGE SAMPLES—*Cont'd*

Remarks		*A*	*B*
(Dry, chloroform extraction)	Grease, ppm	60	60
	pH	7.1	7.1
(As $CaCO_3$)	Total alkalinity, ppm	—	200
(As $CaCO_3$)	Total acidity, ppm	—	38
	Dissolved oxygen, ppm	0.6	—
	Sulfides, ppm	0	0
	Conductivity, $k \times 10^{-5}$ ohm^{-1} @25°C	—	88
(As $CaCO_3$)	Total hardness, ppm	—	91
	Sulfates, ppm	—	15
	Chlorides, ppm	80	118
	Temperature, °F	74	—

Laboratory Procedure:

The coagulation tests were conducted with the usual laboratory stirring device with a battery of eight 200 ml jars equipped with stirrers revolving at 72 rpm. Fifteen minutes of stirring followed by 20 minutes of settling or quiescence were allowed. After the twenty minute period of settling the top 100 ml were poured off, and reserved for test measurements. It has been found that under laboratory conditions a 20 minute settling period gives results which are roughly equivalent to those obtained with the longer detention periods used in plant practice. Chemicals were added just prior to the sitrring, and for each sample the clarification effected by stirring without chemicals was also determined.

Raw sewages were used for the routine coagulation studies. A number of comparative tests were made with different chemicals using both raw sewage and sewage from which the settleable solids had been removed; and in all cases the results were approximately the same. This demonstrates, as has been experienced elsewhere, that it is the suspended matter which is not removed by primary treatment which is responsible for the coagulation demand.

In these studies three principal coagulants were used: Alum, $Al_2(SO_4)_3 \cdot 18H_2O$; ferric chloride, $FeCl_3 \cdot 6H_2O$; and a commercial Wyoming bentonite, designed Bentonite "B," with which $CaCl_2$ was also added. Limewater, sodium hydroxide, and sulfuric acid were also used, and although clarification could be effected with any of these chemicals alone, their chief use was for pH adjustment, i.e., for improving the action of the primary coagulants. These chemicals were prepared in solutions of 200 gr./gal. strength, with the exception of limewater, for which a saturated solution was used. A mechanical mixer was used for preparing the bentonite suspensions.

In addition to the coagulation tests, studies were made of the clarification effected by plain sedimentation of the raw sewage in the 200 ml jars. These data, illustrated by Figure 6, are discussed separately.

The basic laboratory data for each of the 16 samples are presented in Table II. The table includes characteristics of the untreated sewage, removals of suspended material effected at various stages of clarification, and required chemical dosages.

Estimating the Efficiency of Coagulation:

The turbidity measurement was adopted as the principal criterion of

clarification, and this measurement was made on all test portions. Turbidities over 100 ppm were measured with the Jackson turbidimeter; under 100 ppm with standards prepared by dilution of some of the sewage which had been previously stirred and settled. Simple turbidity measurements were found to be a reliable criterion for estimating the removal of both suspended solids and B. O. D.* This was established by correlating turbidity, suspended solids, and B.O.D. on a large number of samples. Figure 1 illustrates these average relationships for a typical sewage sample at various stages of clarification. The turbidity-suspended solids curve, obtained from suspended solids determination on samples of large volume, is approximately a straight line, which on extrapolation passes through or near the origin. The turbidity-B.O.D. curve also approximates a straight line; and on extrapolating this line to zero turbidity an intercept is obtained which represents the approximate residual B.O.D. not removable by simple clarification.

It is believed that in general the turbidity-B.O.D. and turbidity-suspended solids curves for fresh domestic sewages will approximate broken lines, i.e., two straight-line segments, with the change in slope at or near the point corresponding to the division between clarification by stirring and sedimentation without chemicals and clarification by the same treatment with chemicals.

*Similar relationships have been reported by other investigators, most recently by Bell (1).

The Critical Zone in the Turbidity-Dosage Curve, and the Method of Presenting Coagulation Data:

Figure 2 shows typical removals of suspended matter effected by varying chemical dosages. These curves are characterized by a critical break or bend region beyond which clarification cannot be attained economically. This break usually occurs in the final turbidity range of about 50-20 ppm. Beyond this region the curve gradually flattens out, and eventually, at very large dosages, will gradually rise. In the coagulation of turbid waters there is usually a much sharper rise, resulting in a definite minimum point, designated as "optimum." The coagulation data are given in terms of the chemical dosages required to reduce the final turbidity to two selected values, 50 ppm and 30 ppm, representing the approximate limits of economical clarification.

For further simplicity the coagulation data have been referred to a hypothetical or typical (primarily domestic) sewage of 300 ppm 5-day B.O.D.* (Figure 1). This sewage would have a corresponding suspended solids concentration of 313 ppm and a turbidity of 285 ppm. After 15 minutes stirring (without chemicals) followed by 20 minutes settling, the residual turbidity would be 125 ppm, corresponding to B. O. D. and suspended solids values of 168 ppm and 137 ppm, respectively. After clarification with chemicals, at 50 ppm final turbidity, the residual B.O.D. and suspended solids concentrations would be 103 ppm and 57 ppm respectively. At 30 ppm final turbidity these would be 87 ppm and 34 ppm, respectively. Computations were made to determine whether or not these reductions are in-

*Curves similar to those shown in Figure 1 were prepared with the average data for the 16 samples. From these curves the suspended solids and turbidity values corresponding to 300 ppm B.O.D. were obtained. The percentage removal of suspended matter which would be effected in this typical sewage by a particular clarification process was taken equal to the average percentage removal for the 16 samples.

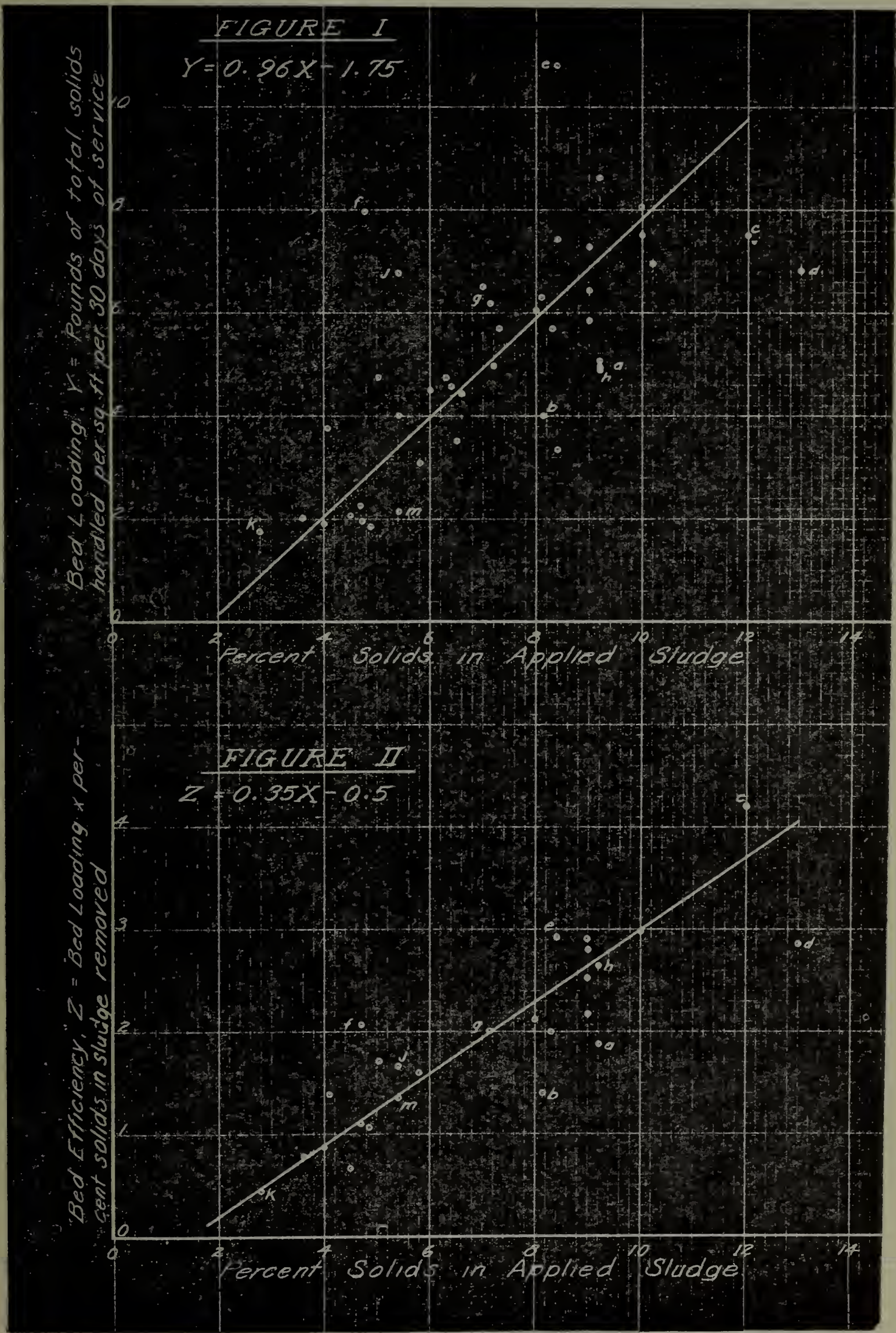


FIGURE I
Y = 0.96X - 1.75
Bed Loading: Y = Pounds of total solids handled per sq. ft. per 30 days of service
Percent Solids in Applied Sludge
FIGURE II
Z = 0.35X - 0.5
Bed Efficiency, Z = Bed Loading x per-cent solids in sludge removed
Percent Solids in Applied Sludge

dependent of the kind of chemicals used. For each B.O.D. test made on samples having a final turbidity of from 50 to 30 ppm, the ratio, % reduction in B.O.D. to % reduction in turbidity, was computed; and its average value for each coagulant was as follows: Bentonite, 78%; ferric chloride, 78%; alum, 79%; and limewater, 80%.

The dosages for the individual samples were expressed in terms of the concentration of chemicals required for removing unit concentration of either the total B.O.D. of the raw sewage or of the residual B.O.D. after clarification by stirring without chemicals. For comparative purposes the former method is satisfactory, and has the advantage of simplicity.

Flocculation Without Preliminary Adjustment of pH:

Figure 2 summarizes results of the simple coagulation studies employing alum, $Al_2(SO_4)_3.18H_2O$; ferric chloride, $FeCl_3.6H_2O$; and Bentonite "B." Of the three coagulants, only alum gave satisfactory results for all sixteen samples. In each case the turbidity reduction-dosage curve was characterized by an initial rise followed by an abrupt drop. Ferric chloride proved satisfactory for 10 of the samples, and for these the turbidity reduction-dosage curves were similar to those obtained with alum. For the remaining six samples, excessively large dosages were required and even then the floc characteristics were relatively poor. The curves for these samples did not have the abrupt drop but instead remained approximately linear beyond the initial rise. In the case of bentonite, the samples again divided into essentially the same two groups, 10 samples for which the final turbidity could be reduced to 30 ppm and six samples for which a final turbidity less than about 50 ppm could not be obtained with any amount of bentonite. In plotting the results it seemed desirable to provide separate curves for each of these groups as well as a mean curve for all the samples. Such curves are given in Figure 2, and from these may be taken the dosages required for effecting the desired reductions in turbidity for the typical sewage of 300 ppm B.O.D. On a grain per gallon basis alum is the most efficient, the required dosages for effecting final turbidities of 50 and 30 ppm having mean values of 4.1 and 4.9 gr./gal., respectively. This is equivalent to about 2.2 gr./gal./100 ppm B.O.D. removed, with reference to the raw sewage, and equivalent to about 6.2 gr./gal./100 ppm B.O.D. removed, with reference to the sewage after clarification by 15 minutes stirring (without chemicals) followed by 20 minutes settling. The corresponding values for ferric chloride are about 1.8 times as great, and for bentonite about 1.4 times as great. In the latter case there must also be added roughly 5 gr./gal. of $CaCl_2$, which was found necessary to render the bentonite effective. These various dosages are summarized in Table II.

It is noted that the shape of the turbidity reduction-dosage curves for bentonite is markedly different from that for alum or ferric chloride. The bentonite curves lack the initial rise and subsequent abrupt drop, and instead are approximately linear, so that removals are roughly proportional to dosages, even for small dosages, down to a final turbidity of about 50 ppm. The rise in the initial section of the alum and ferric chloride curves indicates that small amounts of these chemicals do not effect any appreciable removal of suspended matter. The added chemical is probably converted to the hydrous oxide, which remaining in suspension increases the turbidity.

General Characteristics of the Sewage Samples

Number (Arabic number designates sewer)	Industrial Wastes Present	B.O.D. p.p.m. 5 day (20°C)	Suspended Solids - p.p.m.	Turbidity p.p.m.	pH	Conductivity K × 10⁻⁵ ohm⁻¹	Total Hardness @ CaCO₃ p.p.m.	Total Alkalinity @ CaCO₃ p.p.m.	Chlorides Cl⁻ p.p.m.	Grease p.p.m.
1A	None	230	178	225	7.1	x	95	220	60	12
2A	Creamery	495	424	420	7.4	x	x	275	53	39
2B	Laundry wastes	388	296	300	7.0	x	120	195	116	81
2C		325	365	280	7.5	80	84	330	76	92
3A	None	300	350	300	7.3	x	117	290	56	70
3B		248	282	225	7.2	74	120	195	55	81
4A		190	167	200	6.7	58	77	145	50	60
4B		315	370	305	6.9	45	28	160	60	x
5A	None	358	419	450	7.2	147	153	230	250	65
5B		365	413	420	7.3	287	150	255	630	90
6A	Cannery and	450	309	300	6.5	65	52	95	89	70
6B	Acidulated wastes	395	374	360	6.7	53	98	150	40	64
6C		298	430	350	6.7	x	50	150	x	x
7A	None	290	550	340	7.2	48	110	195	40	x
8A	Small	280	237	215	7.2	64	55	150	82	x
8B	Industry	260	266	265	7.1	47	52	200	x	x
No. of Samples		16	16	16	16	11	15	16	14	11
Mean		320	340	285	7.1	88	91	200	118	60
Typical Sewage[1]		(300)	(313)	(285)	(7.1)	(88)	(91)	(200)	–	-

Removal of Suspended Matter at Various Stages of Clarification

Number	15 minutes stirring + 20 minutes settling[2]: Residual Turbidity p.p.m.	15 minutes stirring + 20 minutes settling[2]: B.O.D. p.p.m.	Residual B.O.D. p.p.m. after clarification with chemicals — Residual or Final Turbidity 50 p.p.m.	30 p.p.m.	0 p.p.m.[3]
1A	100	126	81	63	40
2A	130	230	147	126	110
2B	100	203	147	125	100
2C	135	167	97	82	60
3A	95	136	98	82	60
3B	70	110	90	70	50
4A	80	97	76	63	45
4B	160	225	92	84	50
5A	180	195	103	88	65
5B	160	193	115	100	80
6A	150	294	203	185	140
6B	140	206	120	106	90
6C	185	205	112	98	80
7A	190	164	63	49	25
8A	140	172	103	88	65
8B	145	157	105	87	45
No. of Samples	16	16	16	16	16
Mean	–	–	-	–	–
Typical Sewage[1]	(125)	(160)	(103)	(87)	(68)

Required Chemical Dosages (Gr./Gal.) without Preadjustment of pH

Number	Final Turbidity = 50 p.p.m.: $Al_2(SO_4)_3 \cdot 18H_2O$	$FeCl_3 \cdot 6H_2O$	Bentonite "B"	Bentonite "B" + $CaCl_2$	$Ca(OH)_2$	NaOH	H_2SO_4	Final Turbidity = 30 p.p.m.: $Al_2(SO_4)_3 \cdot 18H_2O$	$FeCl_3 \cdot 6H_2O$	Bentonite "B"[5]	$Ca(OH)_2$
1A	3.3	3.0	3.0	5.0	4.2	x	x	5.0	4.3	3.0	8.0
2A	5.6	10.0	x	x	7.5	x	x	6.5	12.	x	9.0
2B	4.8	8.5	3.0	7.0	5.2	x	x	5.4	11.	5.0	7.6
2C	6.4	11.6[4]	8.8	2.0	7.2	11.	23	6.8	12.5[4]	N.P.[6]	8.5
3A	2.7	4.5	8.0	5-10	7.1	x	x	3.3	5.6	N.P.	9.0
3B	2.4	4.1	1.5	5-10	7.0	x	x	3.4	6.0	3.3	11.
4A	2.0	2.3	1.2	5-10	5.0	x	x	2.6	3.3	9.0	6.2
4B	6.9	11.[4]	10.0	5.0	7.8	10.	25	6.1	12.[4]	N.P.	10.
5A	4.2	5.6	9.0	4.0	8.6	x	x	5.0	7.0	11.	11.
5B	4.0	6.0	5.1	5-10	5.7	x	x	5.9	8.0	8.0	7.0
6A	6.2	14.[4]	3.0	1.0	8.5	x	x	7.0	15.[4]	5.0	11.
6B	3.0	7.0	5.6	5.0	9.0	x	x	3.5	8.0	10.	11.
6C	6.7	11.[4]	10.	5.0	8.0	10.	13	7.2	12.[4]	N.P.	12.
7A	4.3	8.7	3.6	1.0	8.0	11.	23	5.0	3.6	8.0	9.3
8A	5.0	12.[4]	10.	2.0	4.0	6.0	15	5.5	15.[4]	N.P.	5.0
8B	3.5	8.0[4]	4.5	5-10	6.5	8.5	18	4.8	9.7[4]	N.P.	7.7
No. of Samples	16	16	15	15	16	6	6	16	16	9	16
Mean	–	–	–	5.0	–			–	–	–	–
Typical Sewage[1]	(4.1)	(7.4)	(5.6)	(5.0)	(6.5)	(10)	(20.)	(4.9)	(8.9)	(–)	(8.5)

[1] Hypothetical typical sewage: 300 p.p.m. Initial B.O.D. - See Discussion

[2] Extrapolation (See Fig. 1)

[3] For additional data See Fig. 6

[4] Poor floc characteristics

[5] $CaCl_2$ dosages same as for final Turbidity of 50 ppm.

[6] N.P. = Not possible to lower the final turbidity below about 50 p.p.m.

Table II

The action of bentonite differed again from that of alum and ferric chloride in the matter of volume and type of floc. With bentonite greater volume of floc was produced per unit weight of coagulant, but this floc sometimes did not settle as rapidly as did the alum and ferric chloride flocs.

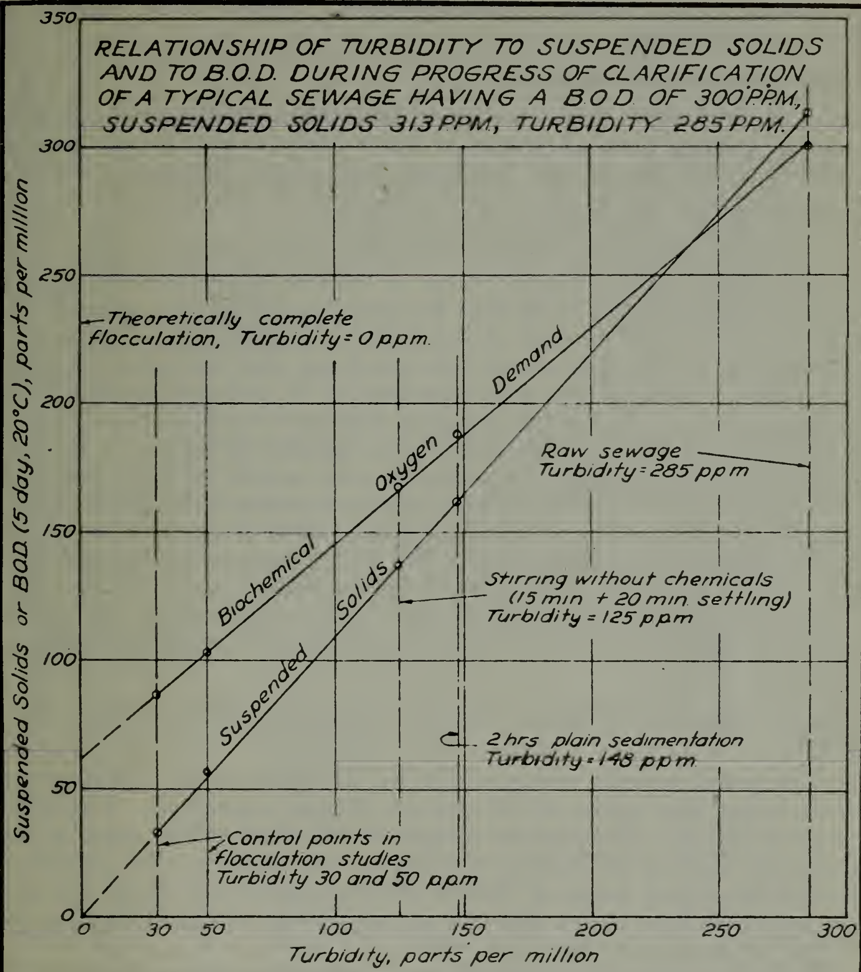
Regarding the ultimate removals which could be obtained, it was observed that with alum the turbidity generally could be lowered to 10 ppm or less by an appropriate increase in dosage. This was sometimes not possible with ferric chloride, and frequently not possible with bentonite.

Effect of the Divalent Cation Concentration:

It should be noted here that the action of bentonite clay in clarification practice is fundamentally different from that of the metal coagulants, aluminum and iron. Whereas when alum is used a good floc will form only in the presence of finely divided suspended matter, bentonite will form a good floc of itself in the absence of such suspended particles, provided there is present a sufficient concentration of divalent cations. When finely divided suspended matter is also present, this will be removed by the sweeping and entrapping action of the bentonite floc. The use of bentonite as a coagulant is therefore dependent upon the presence of a minimum concentration of divalent cations. In these studies it was found necessary to add from one to 10 gr./gal. of $CaCl_2$ in combination with the Bentonite "B" dosages. On the average 5 gr./gal. $CaCl_2$ were necessary, and this increased the divalent cation concentration from the original average value of 91 ppm (as $CaCO_3$) to a total value of about 170 ppm (as $CaCO_3$). For individual samples, however, the total divalent cation concentration varied widely from this mean. The optimum $CaCl_2$ dosage for each sample was estimated by combining various bentonite dosages with $CaCl_2$ dosages ranging from zero to 15 gr./gal., and noting the minimum $CaCl_2$ dosage which seemed necessary for good results.

A study was also made to determine the "flocculating value" of Bentonite "B," i.e., the dosage of $CaCl_2$ required for clarifying a suspension (10 gr./gal.) of this bentonite in distilled water (buffered with a little $NaHCO_3$), with the usual conditions of 15 minutes stirring and 20 minutes settling. It was found that between 30 and 40 gr./gal. of $CaCl_2$ were required. In subsequent work with sewage samples it was observed that the clarifications effected by this bentonite could be improved considerably by utilizing $CaCl_2$ dosages of about 40 gr./gal., but that little improvement resulted from increasing the $CaCl_2$ dosage above the optimum value determined as outlined above unless the dosage was about 20 gr./gal. or more. As a result of these observations a study was made of the clarifying capacities of other clays with lower flocculating values.

Certain other studies demonstrated that the dosages of alum or ferric chloride required for coagulation of individual samples are dependent somewhat upon the divalent cation or hardness concentration. Rudolfs and Gehm (2) have found similar relationships. The author's experience in the coagulation of both sewages and turbid waters indicates that if a certain minimum concentration of these cations is not present the required coagulant dosage will be abnormally large, and that the addition of some divalent cation might be advisable. When the initial hardness is appreciable, however,



Turbidity	5-day B.O.D.		Suspended Solids	
p.p.m.	p.p.m.	%	p.p.m.	%
285	300	100	313	100
148	188	63	163	52
125	168	56	138	44
50	103	34	57	18
30	87	29	34	11
0	63	21	0	0

Plotted points represent average values for 16 representative samples from 8 sewers.

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RELATIONSHIP OF TURBIDITY TO SUSPENDED SOLIDS OR B.O.D.

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Figure 1

the resulting reductions in coagulant are small relative to the amount of divalent cation added.

Effect of Industrial Wastes:

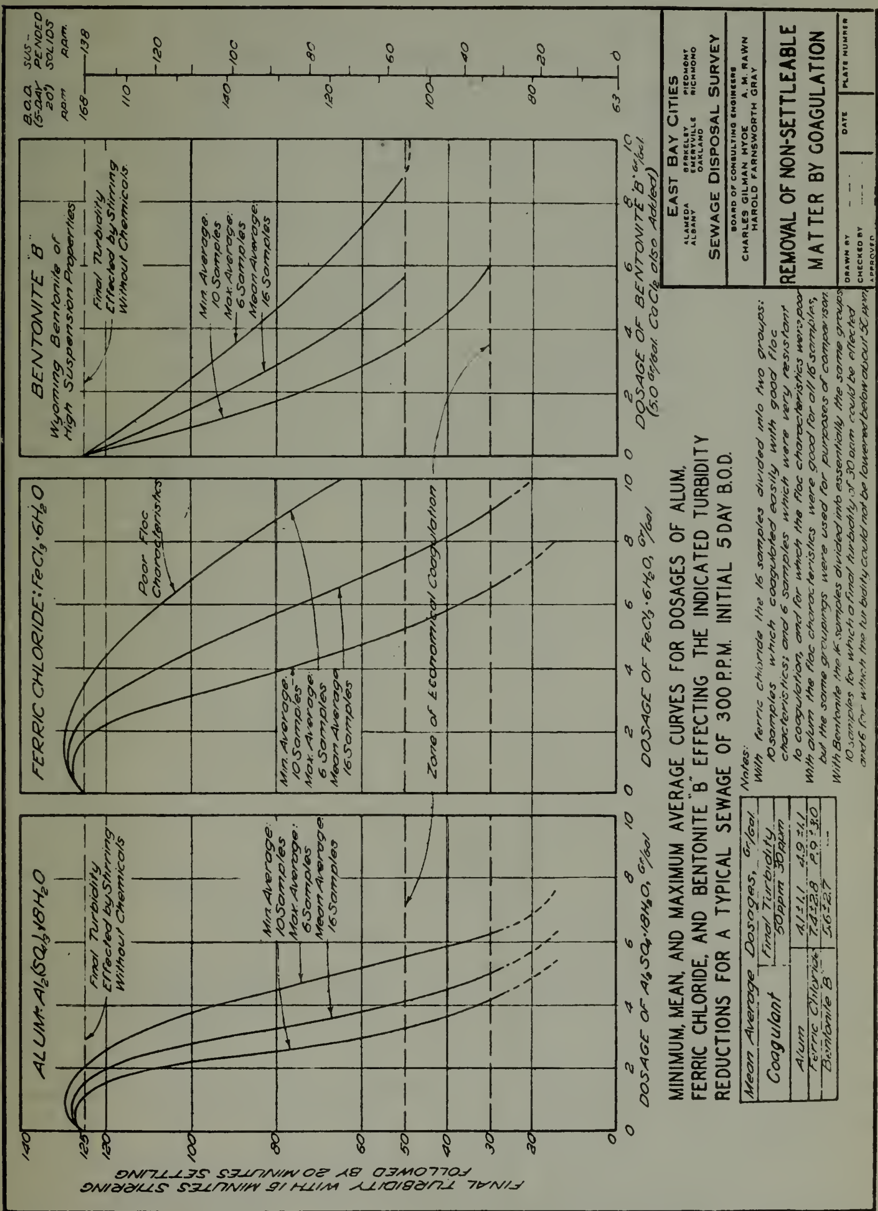
It has been noted that about six of the sewage samples were especially resistant to coagulation. Reference to Table II shows that five of these are included in those eight samples known to contain some industrial wastes. It is concluded that the coagulation of such mixed wastes generally requires more chemicals per unit removal of total B.O.D.

In this connection it is desired to comment on some studies made on sewages containing much industrial wastes in addition to the domestic wastes. For four different sewers in the East Bay area sampling stations were selected both above and below the zone of industrial waste discharge, and composites were obtained of the same sewage flow before and after the inflow of industrial wastes. These samples were coagulated to 50 ppm final turbidity with alum, and B.O.D. and oxygen consumed tests were made on both the raw and clarified sewage. For the lower station samples the values for B.O.D., oxygen consumed, and coagulant demand were usually much greater than for the upper station samples, but the relative increases in oxygen consumed and coagulant demand were considerably more than the increase in B.O.D. As a consequence the value of the alum dosage expressed in gr./gal./unit removal of oxygen consumed was more nearly constant for both stations than the corresponding expression for B.O.D. This indicates that the oxygen consumed might be a superior basis of comparison in coagulation studies of such combined wastes.

The pH Adjusting Reagents: Buffer Curves and Flocculation Effects:

The typical domestic sewage sample has an initial pH of 7.1 and a total alkalinity and total acidity of 200 ppm and 38 ppm, respectively. The buffer curves of Figure 3 illustrate the changes in pH which would occur in this sample by addition of H_2SO_4, $Ca(OH)_2$, and NaOH. For individual samples the gr./gal. dosage of NaOH effecting a given pH change was usually somewhat more or less than the gr./gal. dosage of $Ca(OH)_2$, but the average values did not differ materially.

The independent coagulation effects of these pH adjusting chemicals are given also in Figure 3. Limewater, $Ca(OH)_2$, was quite effective, and dosages of about 6.5 and 8.5 gr./gal. (about 1.75 times the corresponding alum dosages) effected the specified 50 ppm and 30 ppm final turbidities, at pH's of about 9.3 and 9.4, respectively. As indicated by the diagram, turbidities generally could be reduced below 30 ppm by an appropriate increase in dosage. The floc characteristics were generally good, but occasionally the floc was somewhat fluffy and slow-settling as compared with alum. With sodium hydroxide very similar results could be obtained, but with much larger gr./gal. dosages, at a pH of about 10.5; and the flocs were sometimes fluffy and slow-settling as compared with those for limewater. As indicated by both B.O.D. and the turbidity measurements, large dosages (up to 50 gr./gal.) of limewater and sodium hydroxide generally did not cause redispersion. With sulfuric acid, a dosage of roughly 20 gr./gal. produced a fragile, fluffy, poorly settling floc, at a pH of about 2.5, which resulted in a


ALUM: $Al_2(SO_4)_3 \cdot 18H_2O$
FERRIC CHLORIDE: $FeCl_3 \cdot 6H_2O$
BENTONITE "B"
Wyoming Bentonite of High Suspension Properties
Final Turbidity Effected by Stirring Without Chemicals
Min Average: 10 Samples
Max Average: 6 Samples
Mean Average: 16 Samples
Poor Floc Characteristics
Zone of Economical Coagulation
DOSAGE OF $Al_2(SO_4)_3 \cdot 18H_2O$, Gr/Gal
DOSAGE OF $FeCl_3 \cdot 6H_2O$, Gr/Gal
DOSAGE OF BENTONITE "B" Gr/Gal (5.0 Gr/Gal $CaCl_2$ also Added)
FINAL TURBIDITY WITH 15 MINUTES STIRRING FOLLOWED BY 20 MINUTES SETTLING
B.O.D. (5-DAY 20°) P.P.M.
SUSPENDED SOLIDS P.P.M.
MINIMUM, MEAN, AND MAXIMUM AVERAGE CURVES FOR DOSAGES OF ALUM, FERRIC CHLORIDE, AND BENTONITE "B" EFFECTING THE INDICATED TURBIDITY REDUCTIONS FOR A TYPICAL SEWAGE OF 300 P.P.M. INITIAL 5 DAY B.O.D.
Mean Average Dosages, Gr/Gal
Coagulant | Final Turbidity 50 ppm | 30 ppm
Alum | 4.1±1.1 | 4.9±1.1
Ferric Chloride | 7.4±2.8 | 8.0±3.0
Bentonite B | 5.6±2.7 | ...
Notes:
With ferric chloride the 16 samples divided into two groups: 10 samples which coagulated easily with good floc characteristics; and 6 samples which were very resistant to coagulation, and for which the floc characteristics were poor.
With alum the floc characteristics were good for all 16 samples, but the same groupings were used for purposes of comparison.
With Bentonite the 16 samples divided into essentially the same groups: 10 samples for which a final turbidity of 30 ppm could be effected and 6 for which the turbidity could not be lowered below about 50 ppm.
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REMOVAL OF NON-SETTLEABLE MATTER BY COAGULATION
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Figure 2

final turbidity of about 50 ppm. Additions of more acid generally caused redispersion, although occasionally the floc was improved and the turbidity further lowered.

Flocculation With Preliminary Adjustment of pH:

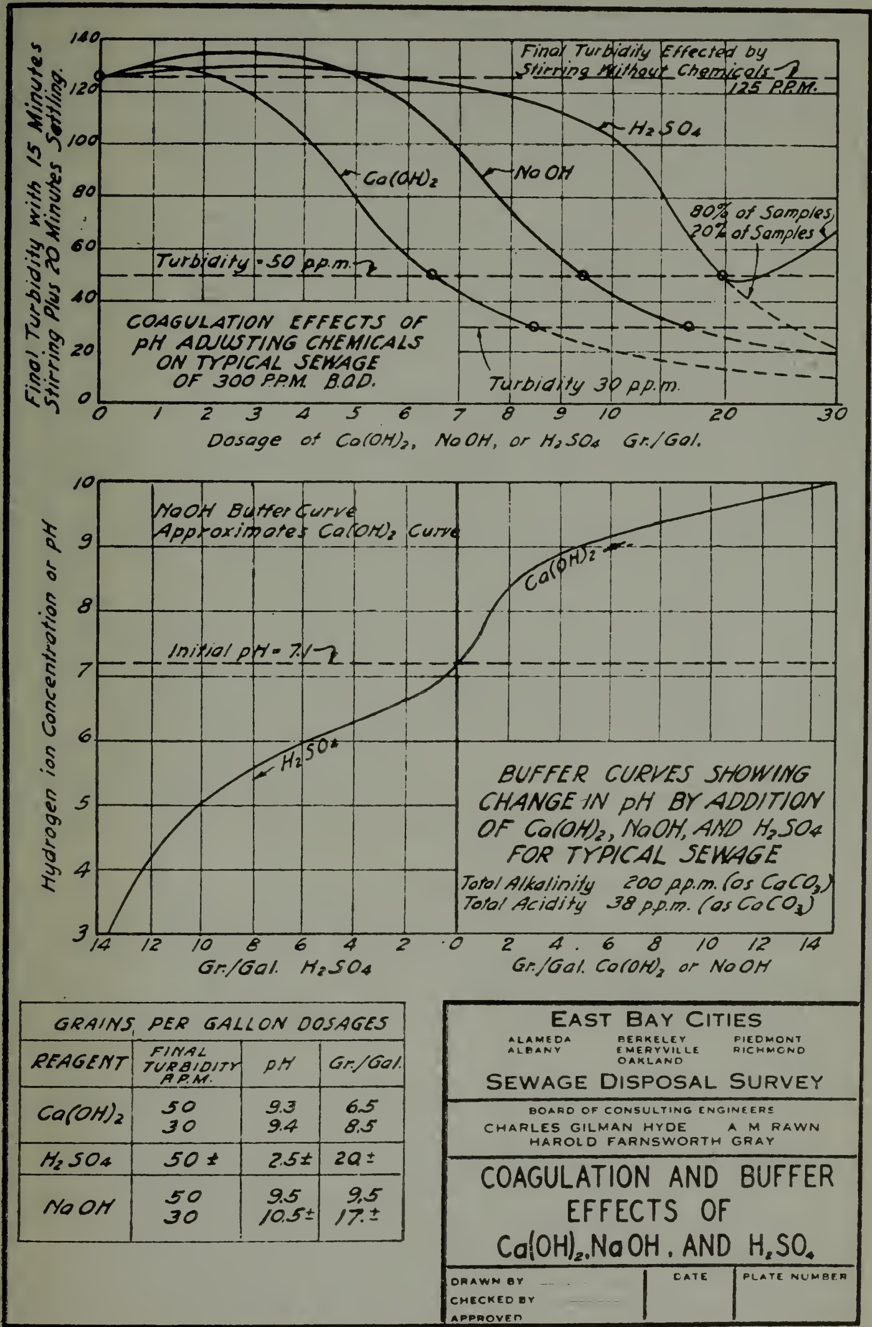
Figure 4 summarizes results obtained for five of the sewage samples (Nos. 4B, 6C, 7A, 8A, Table II) when the coagulants (alum, ferric chloride, and Bentonite "B") were used in combination with either sulfuric acid or limewater. The curves give the dosages of these coagulants which would be required for effecting 50 ppm final turbidity for any preadjusted pH. The curves for a final turbidity of 30 ppm would be similar in shape. Inasmuch as both the acid and limewater have significant independent coagulating effects, it is not surprising that the coagulant dosages could be decreased by either raising or lowering the pH. For practically all the samples it was observed that the raw sewage as sampled was at or near a condition of maximum stability, and that clarification was facilitated by any preadjustment of pH in either direction. Rudolfs and Gehm (2) have found a similar relationship. With ferric chloride, clarification could be effected at any point in the pH range studied, the more limewater or sulfuric acid added the less the necessary dosage of ferric chloride. Best results were obtained, however, at pH about 6 or below, or about 8 or above. In the neutral pH range, about 6.0 to 8.0, the action of ferric chloride is sometimes inhibited, as already noted; so that both excessive dosages and poor floc characteristics result. With alum, good results were obtained in this neutral pH range, but on the other hand the alum dosages could not be greatly reduced by preliminary adjustment of pH. Outside the pH range about 4.5 to 8.0 an effective alum floc does not form. Bentonite resembled ferric chloride in its behavior in that at either high or low pH's small dosages effected good clarification; in these ranges the bentonite dosage is approximately a linear function of the pH. The required accompanying dosage of $CaCl_2$ also diminished with the addition of limewater or sulfuric acid, and in either very acid or alkaline solution was, as near as could be determined, practically nothing.

A few tests were also made with sodium hydroxide as a pH adjustor, and the resulting curves were somewhat similar to those obtained with limewater. The latter reagent was adopted for this function, however, because of the additional coagulating effect of the calcium ion.

Evidently good clarification may be secured at almost any pH with an appropriate selection of chemicals; and the "optimum" pH will be that which happens to be associated with the cheapest combination of reagents effecting the desired results.

Bentonites: Correlation Between Clarifying Capacity and Suspension Properties:

The commercial Wyoming bentonite clay adopted as the standard for the coagulation studies has a high "flocculating value," as already noted. Such a bentonite is sometimes referred to as being very "stable" or having "high suspension properties," because an aqueous suspension of the clay will remain suspended for a long period of time. In order to determine whether or not a bentonite suitable for sewage clarification should be highly stable, seven



GRAINS PER GALLON DOSAGES			
REAGENT	FINAL TURBIDITY P.P.M.	pH	Gr./Gal.
$Ca(OH)_2$	50 30	9.3 9.4	6.5 8.5
H_2SO_4	50 ±	2.5±	20 ±
NaOH	50 30	9.5 10.5±	9.5 17.±

Figure 3

other clays*, ranging from very high to very low suspension properties, were selected for study. All eight clays were compared as coagulants for various sewages under varying conditions of added chemicals; and in general their relative clarifying capacities assumed a definite order. Alphabetical designations were assigned accordingly, from "A" for the best clay, to "H" for the least effective; these may be further grouped as follows: A, excellent; B, C, D, good; E, fair; F, poor; and G and H, ineffective.

The relative stabilities of these clays were determined first by simply observing how much of an aqueous suspension would settle out on standing. These data were supplemented by two other stability tests to determine: (1) The dosage of calcium chloride required to flocculate a 10 gr./gal. aqueous suspension (reduce the turbidity to 15 ppm with 15 minutes stirring plus 20 minutes settling) ; and (2) the weight of methylene blue (a basic dye) absorbed by 200 ml of a 100 gr./gal. aqueous suspension. The results of these measurements are given in Figure 5, in which it is seen that the three stability tests are correlated. The pertinent observation, however, is that there is apparently little relationship between clarifying capacity and suspension properties; in fact, for the bentonite clays, Bentonite "A" suspension was the least and Bentonite "B" the most stable. The bleaching clays, G and H, which have very great dye absorption capacity but which do not form a stable suspension, have practically no clarifying action. Evidently the clarifying capacity of a bentonite must be associated primarily with some other property, possibly its tendency to agglomerate or its ability to bind other particles together. The best bentonite would presumably be that having the requisite agglomerating nature and also a relatively low stability, so that it could be easily removed from suspension after having been added. It is believed that by use of the proper bentonite the required accompanying $CaCl_2$ dosage will be small, and, also, that the values of the bentonite dosages which were obtained in the coagulation studies with Bentonite "B" are probably considerably greater than those which would have been obtained had a bentonite like "A" been used.

It is of interest to note that the shape of the typical turbidity reduction-$CaCl_2$ dosage curve is very much like that obtained for clarification of sewage with alum (Figure 2), having an initial rise followed by an abrupt drop. In this case the initial hump probably results from aggregation of those bentonite particles which are originally so small that they are visible only by diffraction (the Tyndall beam) and therefore do not contribute much to the turbidity.

Plain Sedimentation of Raw Sewage Under Laboratory Conditions:

Inasmuch as all the settling phenomena occurred in 200 ml jars, it is of basic interest to establish the characteristics of plain sedimentation as it occurs in such jars under quiescent laboratory conditions. Figure 6 shows average jar plain sedimentation curves which give the percentage removals of suspended solids (or of turbidity) and of B.O.D. occurring over a varying period of retention (Table III). It was observed that these curves approximate the hyperbolic form, $R=t/(B\text{-}/\text{-}kt)$, where R is the percentage

*Clay samples supplied by Mr. D. Irving of the Industrial Minerals and Chemical Company, Berkeley, California.

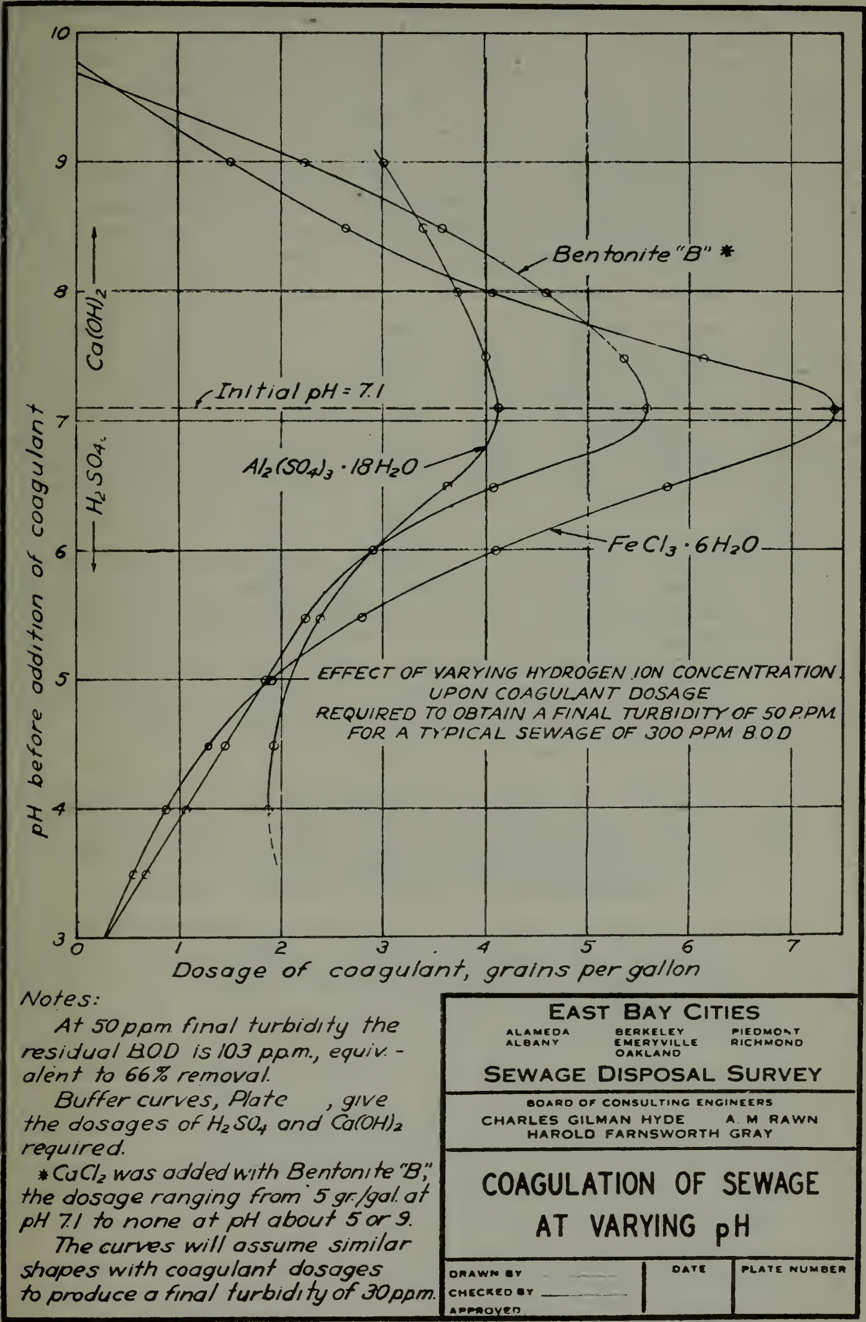

pH before addition of coagulant
Dosage of coagulant, grains per gallon
10
9
8
7
6
5
4
3
0
1
2
3
4
5
6
7
Ca(OH)2
H2SO4
Bentonite "B" *
Initial pH = 7.1
Al2(SO4)3 · 18 H2O
FeCl3 · 6 H2O
EFFECT OF VARYING HYDROGEN ION CONCENTRATION
UPON COAGULANT DOSAGE
REQUIRED TO OBTAIN A FINAL TURBIDITY OF 50 P.P.M.
FOR A TYPICAL SEWAGE OF 300 PPM B.O.D.
Notes:
At 50 ppm. final turbidity the residual B.O.D. is 103 p.p.m., equivalent to 66% removal.
Buffer curves, Plate , give the dosages of H2SO4 and Ca(OH)2 required.
* CaCl2 was added with Bentonite "B," the dosage ranging from 5 gr./gal. at pH 7.1 to none at pH about 5 or 9.
The curves will assume similar shapes with coagulant dosages to produce a final turbidity of 30 ppm.
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Figure 4

removal occurring at a time of retention, t, in hours, and B and k are constants for a particular curve. Equations of this type have been fitted to the data and are shown on the diagram, along with their simpler equivalent straight line forms, viz., $(t/R) = B\text{-}/\text{-}kt$. On the same drawing are shown horizontal lines which represent the average removals obtained by 15 minutes plain stirring (followed by 20 minutes settling); and it was found that these values are closely equal to $(1/k)$, the asymptote of the sedimentation curves. The significance of this relationship is that under laboratory conditions, 15 minutes of plain stirring followed by 20 minutes of quiescent settling will give about the same removals as plain sedimentation over an indefinite period of time.*

Further, when the removals of suspended solids and of B.O.D. were computed as the percentage of the asymptote or "ultimate plain sedimentation removal value," the removals were found to be very nearly the same for both suspended solids and B.O.D. A single equation, $R' = t/(B\text{-}/\text{-}kt)$, may be written, for which R' is the percentage removal of ultimate sedimentation removal for either suspended solids or B.O.D. For this equation, which is not shown on the diagram, the values of B and k are 0.0037 and 0.00992, respectively.

It is of interest to note that the hyperbolic sedimentation equation may be derived rationally, and that the authors have applied this equation to the series of sedimentation curves for the removal of suspended solids published recently by Wittwer (3) for the Rahway Valley Sewage Treatment Plant. The resulting equation for the particular sewage and rectangular tank in question is given by $R = t/(B\text{-}/\text{-}kt)$, where k is a constant, equal to 0.012, and B is given by the expression $B = 0.027 — (0.006xS.S.)$, where S.S. is the initial suspended solids concentration in ppm.

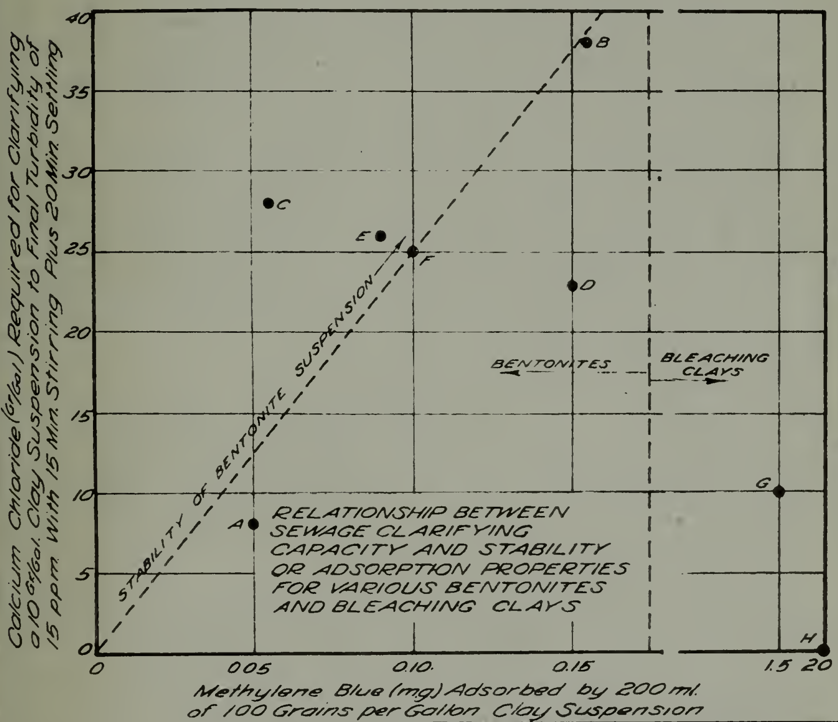
THE MECHANISM OF FLOCCULATION IN WATER PURIFICATION AND SEWAGE PRACTICE, AND ITS RELATION TO THEORETICAL FLOCCULATION DATA

The question arises as to just what is meant when a sewage or a turbid water is "coagulated" or "flocculated." The suspended matter in sewage or turbid water may be roughly classified in two portions: (1) A colloidal fraction of small particles which are in stable equilibrium, i.e., which tend to remain in suspension for a long period of time; and, (2) a non-colloidal fraction of larger particles which are in relatively unstable equilibrium and

*These relationships suggest the feasibility of a standard test procedure which should be useful in evaluating the character of raw sewage in terms of primary and secondary plant loadings. The test procedure would consist of: (1) Measuring the initial turbidity of the raw sewage; (2) stirring (without chemicals) for a definite period, followed by a definite period of quiescence; (3) removing the supernatant and measuring its turbidity; and (4) measuring the volume of the bottom sediment. The residual turbidity would represent that portion of the total suspended matter which may be removed only by secondary treatment. The difference in the two turbidity values would represent that portion which is removable by primary treatment (mixing and sedimentation). The primary treatment loading would be further indicated by the volume of the bottom sediment, which volume might be termed the "total" settleable solids. This measurement would have certain advantages over the standard settleable solids test in that the time requirement is reduced and the solids settle in a more compact mass. The test procedure could be standardized by the use of a specially designed mixing jar with conical bottom and with provision for removal of the supernatant. The combination of turbidity and settleable solids measurements obtained by this procedure would in many cases render the difficult suspended solids determination superfluous.

Clay Designation	Sewage Clarifying Capacity	Stability of Suspension on Standing	Percent Water *	Source and Type
A	Excellent	Moderate	9.0	California Bentonite (Dried)
B	Good	Very high	9.5	Wyoming Bentonite (Prepared)
C	Good	High	9.8	Nevada Bentonite (Crude Ore)
D	Good	High	8.3	Wyoming Bentonite (Dried)
E	Fair	High	8.3	Nevada Bentonite (Dried)
F	Poor	High	10.4	Utah Bentonite (Crude Ore)
G	Little	Little	8.9	Bentonitic Bleaching Clay
H	Very little	None	10.7	Bleaching Clay

* Water content of clays neglected in preparing suspensions.



Notes:

Relative sewage clarifying capacities of clays determined by tests, under varying conditions of added chemicals.

All clays were dried, ground material, excepting "A", a commercially prepared product; and "C and F," crude ores, which were ground in a mortar before using.

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SEWAGE CLARIFYING CAPACITY OF VARIOUS CLAYS

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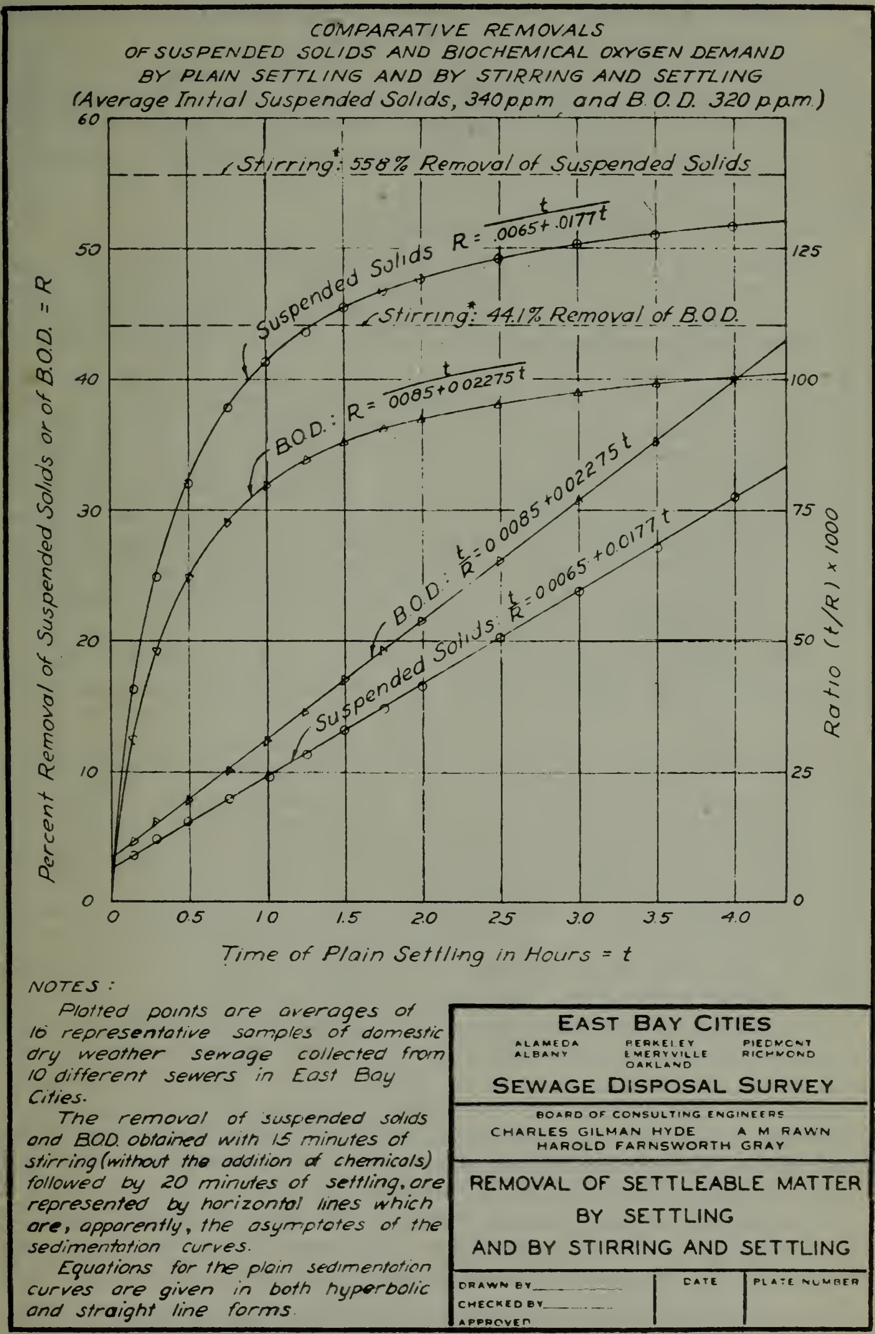
Figure 5

which tend to be removed. We are concerned primarily with the stable fraction of the suspended material, since it is this portion which is responsible for the coagulation demand.

The stability of these colloidal particles results from their small size; the Brownian motion of the water molecules keeps them in suspension. Each particle is surrounded, however, as Smoluchowski postulates, by inherent forces of attraction, so that two particles in close proximity will tend to coalesce, unless this action is prevented by the existence also of repulsion forces greater than those of attraction. In stable colloid systems, the particles are conceived as being surrounded by certain shells or layers, with which are associated the forces of repulsion. If through some action these peptizing layers are removed, the particles will then proceed to coalesce to form aggregates; and the system may be said to be undergoing coagulation. Colloid chemists have termed this process "perikinetic" (4), to denote that the coalescence results from inter-particle attraction forces. It is with this type of coagulation that colloid chemists are primarily concerned. Furthermore, their criterion of coagulation is strictly the reduction in the total number of particles in the system; the system is "coagulated" when the specified reduction has been attained. There may be associated phenomena, such as a settling-out of the aggregates, but these are not essential; for example, if these aggregates are relatively small or are so oriented that they enclose a large amount of water their rate of settling may be small even though coagulation be theoretically complete.

Colloid chemists do, however, distinguish another type of coagulation, termed "orthokinetic" (4), in which the coalescence of the particles is due to mass motion of one group of particles relative to another group, as, for example, during sedimentation of large particles through a suspension also containing smaller particles. This is a mechanical sweeping, combing, and entrapping action, and is evidently the mechanism by which rapid clarification is actually attained in treatment processes.

The complete clarification process will include both these coagulation phenomena, viz., perikinetic coagulation combined with the sweeping and entrapment action of an "orthokinetic floc." A floc of this type is probably always essential for effective clarification; it is needed to sweep the unstable particles from suspension. The importance of the perikinetic reactions will vary, however, depending upon the magnitude and stability of the colloidal fraction. The function of the perikinetic reactions is to remove the stabilizing layers which surround and peptize the colloidal particles; this renders these particles unstable and therefore subject to easy removal by the orthokinetic floc. The necessary orthokinetic floc may be obtained by various means; in the simplest case it may be formed by coalescence of the original suspended matter after this material has been perikinetically coagulated, but usually such a "floc" will be fragile and slow-settling. It is necessary to add some material which will act as a binder and thus will permit the formation of a rapid settling floc with the desired characteristics. The clarifying efficiency of alum, ferric chloride, and similar chemicals, arises from their ability to perform two functions, viz., to release cations which will effect perikinetic coagulation, and to form insoluble hydrous oxide binding material which becomes a major constituent of the orthokinetic floc.


COMPARATIVE REMOVALS
OF SUSPENDED SOLIDS AND BIOCHEMICAL OXYGEN DEMAND
BY PLAIN SETTLING AND BY STIRRING AND SETTLING
(Average Initial Suspended Solids, 340 p.p.m. and B.O.D. 320 p.p.m.)
Stirring*: 55.8% Removal of Suspended Solids
Suspended Solids R = t / .0065 + .0177t
Stirring*: 44.1% Removal of B.O.D.
B.O.D.: R = t / .0085 + .002275t
B.O.D.: t/R = 0.0085 + 0.002275t
Suspended Solids: t/R = 0.0065 + 0.0177t
Percent Removal of Suspended Solids or of B.O.D. = R
Ratio (t/R) x 1000
Time of Plain Settling in Hours = t
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
10
20
30
40
50
60
25
50
75
100
125
NOTES:
Plotted points are averages of 16 representative samples of domestic dry weather sewage collected from 10 different sewers in East Bay Cities.
The removal of suspended solids and B.O.D. obtained with 15 minutes of stirring (without the addition of chemicals) followed by 20 minutes of settling, are represented by horizontal lines which are, apparently, the asymptotes of the sedimentation curves.
Equations for the plain sedimentation curves are given in both hyperbolic and straight line forms.
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REMOVAL OF SETTLEABLE MATTER
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AND BY STIRRING AND SETTLING
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PLATE NUMBER

Figure 6

The term "flocculation" has been used by some investigators (4) to combine the phenomenon of reduction in total number of particles with that of settling to leave a clear supernatant liquid. This differentiation has not been generally recognized by colloid chemists, however, and the two terms are usually defined as being interchangeable. For the purposes of this study, a system is considered coagulated or flocculated when the desired clarification has been obtained.

Nature of the Colloidal Clay Particle:

Although this paper relates primarily to coagulation of sewage, it is desired to discuss also the coagulation of turbid waters. The mechanism of the sewage clarifying processes may be understood more readily by reference to the somewhat less complex phenomena which occur in the clarification of turbid waters. The colloidal fraction of turbid waters is chiefly clay, the stability of which arises from the existence of an electrical double layer surrounding the nucleus or core of each particle (Figure 7). At the surface of the core reside relatively fixed negative charges or anions ("stabilizing ions") which make up the inner part of the double layer, and for the outer part of the layer an envelope of oscillating cations ("counter ions") diffuse into the surrounding dispersion medium (water). The entire particle, including the double layer, is electrically neutral; but such a particle is commonly referred to as a "negative colloid" because it will acquire a negative charge when placed in an electric field.*

When the outer layer extends or dissociates relatively far into the dispersion medium the stability is high, as any two particles so composed are unable to approach each other very closely because of electrical repulsion. As already noted, forces of attraction also extend for short distances around each colloidal particle; and two particles will coalesce when the core of one enters the zone of attraction of another. The presence of the double layer prevents this action, however; and aggregation may take place only after the double layer has been either altogether removed (i.e., the particle rendered isoelectric) or else effectively repressed (to a "critical potential" value). After the double layer has been sufficiently removed, the system is no longer stable, and coalescence occurs as Brownian motion brings the particles together. Prolonged mixing will hasten and extend the process of coalescence, so that aggregates may be built up to much larger size (5).

The stability of the colloid system is measured in terms of electrokinetic or zeta-potential, a quantity which is proportional to the average velocity with which the particles move in an electric field. Coalescence will occur whenever the zeta-potential has been lowered to a certain minimum "critical potential," which for clay suspensoids is of the magnitude of from 20-40 millivolts. (The upper limiting value of the zeta-potential, for the most stable clay colloids, is about 80-100 millivolts.)

The stability of the colloidal particle will depend primarily upon the characteristics of the cations making up the outer layer. The higher the valence and the less the hydrodynamic size of the counter cation, the more

*In an electric field the nucleus of the particle (core and inner layer) and the counter cations are attracted in opposite directions; accordingly, some of the counter cations break away, leaving the nucleus with an excess of negative charges. When the double layer is removed, the particle is "isoelectric" and it does not move in an electric field.

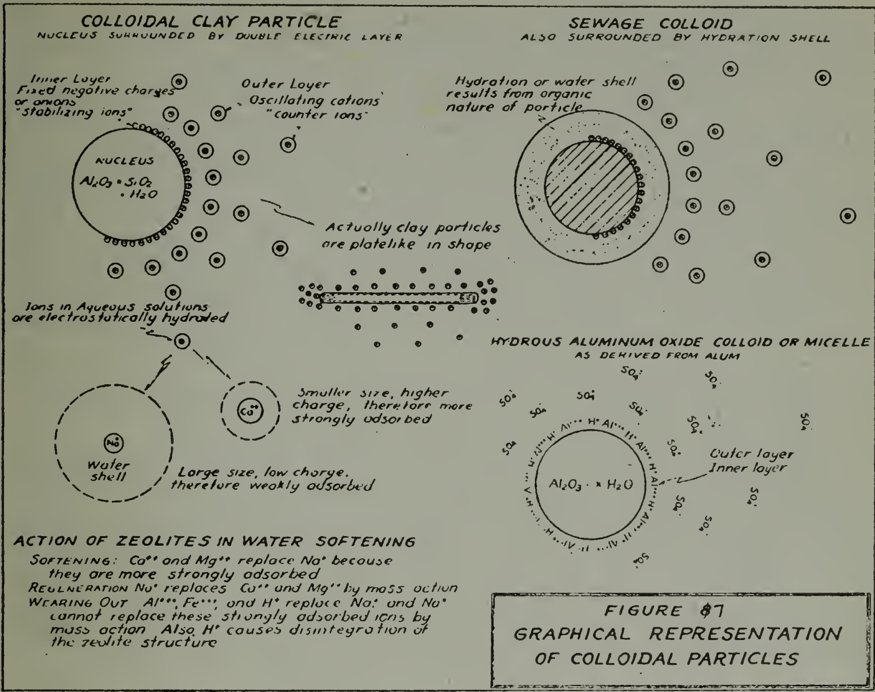

FIGURE #7
GRAPHICAL REPRESENTATION
OF COLLOIDAL PARTICLES

Figure 7

strongly it is held or absorbed by the inner negative layer, resulting in a lower zeta-potential. Ions in aqueous solution are thought to be hydrated or surrounded by a water shell (an electrostatic attraction phenomenon), and in general, for an ion of given valence, the smaller the size of the ion in the crystal lattice the more it will be hydrated in aqueous solution and the greater will be its effective or hydrodynamic size.* The cations commonly found in water, arranged in increasing order of the degree to which they are absorbed, are Na^+, K^+, Mg^{++}, Ca^{++}, H^+, and Al^{+++} and Fe^{+++}. The trivalent Al^{+++} and Fe^{+++} cations, when they exist as such, are very strongly absorbed. The hydrogen ion is anamolous in behavior and acts very much like a weak trivalent cation.

The stability of the colloid system depends also upon the type and concentration of electrolytes in the dispersion medium. An increase in the concentration of these electrolytes will result in shrinkage of the outer layer, an electrical effect known as "repression." A much more important consideration is the possibility that the cations in the dispersion medium may exchange with those in the outer layer, a phenomenon termed "base-exchange" or "adsorption exchange." If to the solution be added cations which have

*The combined effect of valence and of effective size may be expressed in the term, "oscillation volume" (6), representing the effective volume occupied by the oscillating counter cation, or, in other words, the width of the double layer. The smaller the oscillation volume the more strongly the counter cation is adsorbed (the stronger its "exchange adsorbability").

greater "exchange adsorbability," i.e., which are more strongly adsorbed than those in the outer layer, the added cations will supplant or displace the original counter cations, forcing them out into the dispersion medium. The lowering of zeta-potential associated with this exchange is of much greater magnitude than that which results from simple repression. In general, clays with high zeta-potentials have adsorbed ions which are easily exchangeable; and conversely, the coagulating effect of an added cation has been found to increase exponentially with its exchange adsorbability.* It should be noted that exchange adsorption is also governed by the mass law; whether or not one cation will displace another depends not only upon their relative exchange adsorbabilities, but also upon other factors, viz., the relative concentrations of the cations, and the possibility that a unionized product may result and thus drive the reaction in one direction. Whenever a foreign cation is introduced into the system some exchange will always occur; if the concentration of a weekly adsorbed cation be sufficiently high it may quantitatively displace a more strongly adsorbed cation, as in the regeneration of zeolites.

The anions are relatively unimportant in the perikinetic coagulation of negative colloids; they are repelled by the negative inner layer and do not enter into adsorption exchange. The anions of course dominate the coagulation of positive colloids, and the relative exchange adsorbabilities of the various anions will depend chiefly upon valence and hydrodynamic size, as for cations. When positive and negative colloids occur in the same system, "mutual coagulation" may occur; i.e., the oppositely charged colloids attract, combine with, and "neutralize" each other (the double layers disappear).

Flocculation of Turbid Waters:

Since a turbid water is an aqueous suspension of soil, it will contain particles of clay, sand, silt, and some organic matter. The colloidal fraction is largely clay. The majority of clays may be classified as montmorillonite ($Al_2O_3.4SiO_2.H_2O$; $Si/Al=4$) and kaolinite ($Al_2O_3.2SiO_2.4H_2O$; $Si/Al=2$). The characteristics of these clays correlate qualitatively with the Si/Al ratio; the properties of swelling, dispersability, base exchange, and adsorption of basic dyes occur to a greater extent in clays for which this ratio is high. Suspensions of such clays have greater stability and therefore have greater "flocculating value," i.e., require more electrolyte to bring about perikinetic coagulation. The type of counter cations associated with any clay will depend on its origin; in "alkali" clays, for example, Na^+ and K^+ will be predominate in the outer layer. Bentonites are composed largely of such alkali montmorillonites, and are characterized by extreme swelling and very fine particle size. The presence of considerable organic matter greatly increases the stability of the clay particles, and in flocculation properties such particles will resemble those found in sewage. In such systems the organic matter surrounds or "protects" the clay particles, so that the flocculation properties of the colloids are essentially those of the organic phase.

To illustrate the basic phenomena involved in the flocculation of turbid

*The relative coagulating powers of cations of different valence (but equal hydrodynamic size) for certain Putnam clays investigated by Jenny (6) is given not by the Schultz-Hardy rule but by the series, 1I: XII: 2XIII: 3XIV, in which any term represents the amount (mols) of monovalent cation equal to unit amount of polyvalent cation of valence indicated by the Roman numeral. In general, the greater the hydration of the system, the less the applicability of the Schultz-Hardy rule.

waters, it is desired to discuss in some detail a hypothetical turbid water, say a suspension of an alkali clay. The addition to this system of the various coagulants employed in this study ($CaCl_2$, alum or ferric chloride, NaOH or $Ca(OH)_2$, and bentonite) will result in certain phenomena.

The addition of $CaCl_2$ alone will result in a lowering of the zetapotential through the combined effect of repression and of absorption exchange (Ca^{++} replaces Na^+ and K^+), and if enough is added the critical potential will be reached and perikinetic coagulation will occur. A clumping will be effected, but in general this "floc" will not settle rapidly nor will it effectively clarify the system; in other words, an effective orthokinetic floc does not form.* Perikinetic coagulation may also be secured with a monovalent salt like NaCl, but in this case the necessary dosage would be very great, since the only potential reducing process is that of repression.

When alum is added to the system, an additional phenomenon must be considered. At ordinary pH's the alum will dissociate to give Al^{+++} and $SO_4^=$ ions, but the bulk of the Al^{+++} ions will combine chemically with water to form colloidal particles or micelles of hydrous aluminum oxide ($Al_2O_3.xH_2O$), often incorrectly called aluminum hydroxide. This compound contains much more water than would occur in an equivalent amount of $Al(OH)_3$. Figure 7 illustrates the nature of this micelle, and it is seen that the center portion or nucleus of $Al_2O_3.xH_2O$ is surrounded by an electrical double layer. As the hydrous aluminum oxide particles form, they adsorb H^+ and Al^{+++} ions and, consequently, a double layer is set up in which the H^+ and Al^{+++} constitute the fixed stabilizing ions. Those $SO_4^=$ ions originally associated with the adsorbed H^+ and Al^{+++} ions will become the counter ions or outer layer, so that the whole system is electrically neutral. When $AlCl_3$ is used instead of alum, Cl^- ions will constitute the outer layer, unless $SO_4^=$ is present in the dispersion medium, in which case the Cl^- ion will be displaced by the more strongly adsorbed $SO_4^=$.

The stability of these micelles, at a given pH, will depend upon which anions constitute the outer layer.† In the presence of colloidal clay colloids, the hydrous aluminum micelles will lose whatever stability or charge they may have by mutual coagulation with some of the oppositely charged clay colloids. The resulting isoelectric aggregates will combine with each other (agglomerate) and will simultaneously adsorb and entrap the suspended turbidity particles, i.e., build up an orthokinetic floc. Prolonged mixing will greatly improve the agglomeration, as Brownian motion alone results in very small sized floc particles.

As the floc builds up it will entrap the suspended turbidity particles; i.e., these enter into the agglomeration. Since this is essentially an action of coalescence, it follows that the removal of colloidal clay particles by entrap-

*For the case of bentonite clays and orthokinetic floc will result; the clarifying action of bentonite results from this phenomenon.

† In the absence of polyvalent anions, as when $AlCl_3$ is used, the micelle is isoelectric (has no double layer) at pH about 8.0. When the pH is progressively lowered, the core of the particle acquires an increasing positive charge, i.e., a stronger double layer is set up, and the particle becomes more stable (8). When the micelle is derived from alum, or when polyvalent anions are otherwise present, the particle will not acquire much charge even at a low pH because of the high exchange adsorbability of such anions. Whether or not a strongly stable, positively charged micelle is advantageous probably depends upon the amount of oppositely charged colloidal clay available for a mutual coagulation reaction.

ment will be facilitated if the particles have been previously perikinetically coagulated, i.e., if they have been rendered unstable, as by adsorption exchange. In this connection the authors have found that for certain soft waters, which in practice were difficult to coagulate, an improved clarification could be effected by replacing some of the alum with salts releasing divalent cations (e.g., $CaCl_2$ and $MgCl_2$). The dissociation of alum also liberates some H^+ and Al^{+++}, as previously noted; and these also will be effective in bringing about perikinetic coagulation.

There are various evidences which substantiate this pitcure of alum flocculation. For example, it has long been known that the reaction between alum and clay turbidity produces a floc from which the alum can not be recovered by leaching with acid; this indicates that a compound of aluminum oxide and clay is formed, rather than an aluminum hydroxide such as that which results from the neutralization of alum in the absence of clay. Also, the alum floc is known to be most efficient when it builds-up in the presence of the turbidity particles; when the floc is permitted to form in only a portion of the entire batch of water to be clarified, all the turbidity particles do not have opportunity to enter into the agglomeration. Again, when an alum floc is formed in a water very low in turbidity, the floc particles are small-sized, fragile, and slow-settling; this indicates that a minimum concentration of turbidity is needed for participating in either the mutual coagulation process or in the agglomeration of the floc.

According to this picture of alum flocculation, the major part of the added aluminum is converted to hydrous oxide; the process is primarily orthokinetic. These reactions may take place only in a fairly neutral pH range, because in appreciably acid or alkaline conditions the hydrous oxide of aluminum does not form (See Figure 4). The hydrous oxide of iron will form in these extreme pH ranges, so that iron salts will be advantageous when an orthokinetc floc is necessary under very acid or very alkaline conditions.

For certain waters the type of coagulation needed may be essentially perikinetic. In such cases, when alum is needed, it may be desirable to repress the formation of the hydrous oxide so that more of the aluminum will be available as Al^{+++}. The coagulating capacity (capacity to repress or remove the double layer) of the Al^{+++} ion is very much greater than that of an equivalent amount of hydrous oxide (in the former case the process is adsorption exchange; in the latter case, mutual coagulation). The addition of H^+ ions will generally repress the formation of the hydrous oxide (8), and at a very low pH none will form.

Orthokinetic flocculation with alum will depend somewhat on practically every variable in the system ,including the properties of the dispersed phase (the turbidity particles), of the dispersion medium (water and dissolved salts), and of the added reagents. The hydrogen ion concentration is especially important, as this will influence not only the composition, stability, and amount of hydrous oxide micelles produced, but will also influence, because of the high exchange adsorbability of the H^+ ion, the composition of the counter cations in the clay colloids. This pH will therefore largely determine the properties of the alum-clay floc. For any given system, the desired tough, dense, rapid-settling floc will be secured by a certain combination of chemicals (and mixing), with which will be associated a definite pH, which

may be designated as "optimum." It is probably incorrect to speak of an "optimum pH" for a given coagulant, because the pH is only one of the several important variable which control the clarification process. Instead of implying that a particular coagulant functions best at a particular pH, it would be better to state that a given water is best clarified at a certain pH.

When hydroyl ions are added to the hypothetical turbid water, many complex reactions may occur. When a small amount of NaOH is added to a clay containing H^+ counter ions, an ionic exchange results in which the Na^+ replaces the H^+ (which combines with the OH^- ions to form water), increasing the stability of the system. When excessixe OH^- ions are added, the clay complex may decompose (and be precipitated as silicates); and if hardness cations are present, these will be precipitated (this may result in orthokinetic clarification). The use of $Ca(OH)_2$ will have similar effects, with due consideration for the coagulating properties of the Ca^{++} ion.

Clarification of turbid waters with bentonites has been extensively discussed by Olin and his associates (9, 10, 11) and may be explained as a combination perikinetic-orthokinetic process. The electrolyte (e.g., calcium chloride) which must either be already present or added along with the bentonite will perikinetically coagulate the colloidal bentonite particles by the processes of repression and of adsorption exchange. They will then agglomerate to form an orthokinetic floc, which clarifies the system much as does an alum floc. It would seem to follow that a bentonite desirable for flocculation work would have certain properties: (1) The bentonite particles should be highly adsorptive in nature; so that they will act as the binder material in the agglomeration and (2) the bentonite should have a relatively low flocculating value; i.e., it should not be necessary to add excessive amounts of accompanying electrolyte to effect perikinetic coagulation. It is believed that the capacity of an agent such as bentonite or hydrous aluminum oxide to form an orthokinetic or agglomerating floc is associated chiefly with its properties of swelling.

Flocculation of Sewage:

These principles of turbid water flocculation must apply also to sewage; however, the mechanism of sewage flocculation is more complex and has not been as thoroughly investigated. Genter (12) has pioneered work in this field.

The colloidal particle in sewage is surrounded by an electric double layer, and is negatively charged, as before. In addition the particle behaves as if it were surrounded by a very stable "hydration shell," a surface layer which arises from the tendency of organic particles to adsorb water (Figure 8). The flocculation of such hydrophillic colloids requires effective removal of both these stabilizing layers. Whereas in turbid water flocculation the process may be (in the absence of an appreciable colloidal fraction) almost entirely orthokinetic, in sewage flocculation the perikinetic reactions become of major importance; this is because the colloidal fraction of the suspended matter is greater both in concentration and in stability. A sweeping and entrapping floc will effect the actual clarification, but the stabilizing layers must be removed before such a floc will form.

It appears that the same cations which are effective in repressing the electric double layer are similarily effective in removing the hydration shell. Thus Fe^{+++} and Al^{+++}, H^+, Ca^{++} and Mg^{++} are all effective, in the order

named, more or less in proportion to their exchange adsorbabilities. However, the OH^- ion is also effective, and this suggests that the mechanism of dehydration is largely chemical rather than one of adsorption exchange. Polyvalent anions, such as $SO_4^=$, probably also enter into these reactions; and further studies are being made to investigate these relationships.

Rudolfs and Gehm (2) have investigated the source of the coagulant demand of sewage, and state, "the substances present in sewage which are responsible for the coagulation demand consist of the soluble matter plus some colloidal sol of very small particle size; it appears that the coagulant is adsorbed by organic materials present in this form." Evidently these organic materials are the peptizing substances which permit the formation of the hydration shell, and a major portion of the added chemicals is utilized in reacting with these substances. The total coagulant demand will also include, of course, those chemicals which are utilized in removing the electric double layer, and those which are converted to orthokinetc binder material.

Regarding the importance of the electric double layer, little data is available. Eldridge (13) determined the zeta-potential of samples of sewage treated with coagulant, and concluded that there is little relationship between the zeta-potential and the coagulant demand. However, the zeta-potential values which he obtained for the untreated samples were only about 30 millivolts. Since colloidal clay suspensions are generally considered to be unstable when the potential is in this range, it seems probable that the sewages were near the "critical potential" value even before treatment, and, accordingly, no correlation was obtained.

Discussion of the Diagrams:

It has been noted that the presence of divalent cations facilitate the clarification process; for example, the use of $CaCl_2$ reduces the necessary dosage of alum or ferric chloride. However, large dosages of $CaCl_2$ were added to several of the sewage samples, and in only one case was there an appreciable reduction in turbidity. Apparently these cations assist in the perikinetic reactions, but in themselves are not capable of completing them.

Figure 3 shows the flocculation effects of the pH adjusting chemicals, viz., H_2SO_4, NaOH, and $Ca(OH)_2$. Considering first the curve for the acid, it is noted that with a large dosage of H^+ ion a floc could be produced, but that this floc is fragile, slow-settling, and does not reduce the turbidity below about 50 ppm. Evidently the H^+ ion does effectively remove the hydration shell, because the particles coalesce to form a floc, but the absence of a good binder material prevents a really effective orthokinetic action. The extra-addition of only a small amount of bentonite did result in good clarification.

Large dosages of NaOH also produced a floc, but in this case the floc characteristics were good, and effective clarification resulted. The removal of the hydration shell can be attributed only to the action of the OH^- ion; and the clarifying, orthokinetic floc is apparently furnished by the precipitation of insoluble compounds of calcium and magnesium. With limewater, a similar floc was obtained with much smaller dosages. In this case both the Ca^{++} and OH^- ions are perikinetically effective. Compared with alum, the flocs obtained with NaOH or limewater were sometimes fragile and fluffy, indicating that the insoluble compounds of calcium and magnesium are not as efficient binder material as hydrous aluminum oxide.

Figure 2 illustrates the clarification effected by alum, ferric chloride, and bentonite without preliminary adjustment of pH. It is observed that alum is consistently effective, whereas ferric chloride is frequently ineffective. A possible explanation is that at or near pH 7, ferric chloride is not readily converted to the hydrous oxide form (14). This may be especially true in the absence of polyvalent anions, as is the case for these studies, in which the $SO_4^=$ ion concentration averaged only about 15 ppm. When the initial pH is modified to an appreciably acid or alkaline condition, ferric chloride does give clarifications comparable with those obtained with alum. It is also seen that rather frequently the final turbidity could not be lowered below about 50 ppm with bentonite (and $CaCl_2$). This is not surprising, since neither the bentonite nor the $CaCl_2$ added with it is capable of removing the hydration shell. The bentonite releases no dehydrating ions, nor is the $CaCl_2$ in itself adequate. Bentonite does give excellent results in either very acid or alkaline solution.

The shapes of the turbidity reduction curves in Figue 2 indicate the sequence of the clarification phenomena. For alum and ferric chloride the curves have the characteristic initial rise followed by an abrupt drop. Evidently the clarifying orthokinetic action takes place only after enough chemicals have been added to more or less complete the perikinetic reactions. For bentonite, however, the curves are approximately linear, and removals are proportional to the dosages, down to a turbidity of about 50 ppm. This indicates that the action of bentonite is almost entirely orthokinetic. The suspended matter thus removed is probably that portion (of the stable fraction) which is least stable; the remaining suspended matter represents the more stable colloids, the perikinetic coagulation of which is prerequisite to their removal.

In Figure 4 are equilibrium curves which give the necessary coagulant dosages under varying conditions of pH adjustment. As already noted, ferric chloride and bentonite give consistently good results in the extreme pH ranges but not at or near pH 7. Alum, on the other hand, works best in a relatively neutral range, pH about 5 to 8, and loses its orthokinetic efficiency outside this range.

As pointed out in earlier discussion, the suspended matter in sewage includes an unstable fraction; this is the material which tends to be removed by plain sedimentation, and more rapidly, by plain sedimentation preceded by a period of stirring or mixing. These phenomena are illustrated in Figure 6. This unstable fraction may be further subdivided into three portions: (1) The largest particles which are in themselves capable of settling by gravity; (2) particles of smaller size which will not settle until they have coalesced into larger aggregates; and (3) perhaps some colloids of positive sign i,.e., of sign opposite to that of the bulk of the colloids. The particles of the second group are initially slightly stable, but the repulsive forces which prevent their coalescence are of the order of Brownain motion. On standing these particles will coalesce as Brownian motion throws them together, and thus form unstable aggregates which begin to settle out. The particles of the third group will be rendered unstable by mutual coagulation with colloids of opposite sign, as Brownian motion brings such particles into proximity. The purpose of stirring or mixing its to increase the action of Brownian motion, i.e., to increase the number of inter-particle collisions (5), and thus hasten the removal of the latter two groups. The action of stirring apparently

does not increase appreciably the total removal; in other words, it does not affect aggregation of the particles of the stable fraction.

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Table III

Removal of Suspended Solids and B.O.D. (5-Day) in 200 Ml Jars by Plain Sedimentation and by Stirring Without Chemicals for Domestic Sewages With Average Initial Suspended Solids of 340 PPM and B.O.D. of 320 PPM

(Tabular values are averages for 16 samples)

Settling Period Hours=t	Removal=R Per Cent of Original		t Ration R×1000		Removal=R Per Cent of Ultimate	
	Suspended Solids	B.O.D.	Suspended Solids	B.O.D.	Suspended Solids	B.O.D.
0.15	16.3	12.6	9.2	11.9	29	29
0.30	25.0	19.3	12.0	15.5	44	44
0.50	32.1	24.9	15.6	20.1	57	57
0.75	37.9	29.3	19.8	25.6	67	67
1.00	41.3	32.0	24.2	31.3	73	73
1.25	43.7	33.9	28.6	36.9	77	77
1.50	45.4	35.3	33.0	42.5	80	80
1.75	46.8	36.4	37.4	48.1	83	83
2.00	47.8	37.2	41.8	53.8	85	85
2.50	49.1	38.2	5.09	65.4	87	87
3.00	50.1	38.9	59.9	77.1	89	88
3.50	51.2	39.8	68.3	88.0	91	90.5
4.00	51.7	40.2	77.3	99.5	92	91.5
5.00	52.7	41.0	95	122.3	93	93
Ultimate*	56.5	44.0	......	......	100	100
Stirring**	55.8	44.1	......	......	....	....

*Ultimate removal would be that obtained with an indefinite period of retention If the equation of the sedimentation curve is expressed in the form R = t/(B-/-kt), then (1/k) is the ultimate removal, i.e., the asymptote to the curve.

**Removals obtained by 15 minutes stirring (without chemicals) followed by 20 minutes settling.

DETECTION OF METALLIC AND WAR GAS POISONS IN SEWAGE

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April, 1941

A review of engineering magazines from England shows that earth dams, water treatment plants, trunk lines and local reservoirs are bombed wherever such an activity interferes with fire protection. The British report that a single 500-pound bomb dropped in a street forms craters which expose broken ends of both water and sewer lines and that falling debris from buildings many times crushes sewers, fills up manholes and breaks fire hydrants and covers valve locations. In one instance, the repair of 72 feet of 18″ line required seven days instead of five hours as normally required because of deliberate and incessant bombing.

It is not the purpose of this paper to cause alarm among sewage treatment plant operators that sewage laboratory procedures should be immediately revised to detect the presence of metallic and war gas poisons in sewage. Nor is it the intention to infer that this country is about to be subject to a bombardment, aerial attack or an era of sabotage which might endanger water supplies or sewerage works. There is, however, need of augmenting the present number of sewage tests contained in "Standard Methods of Water Analysis" so that operators may streamline the operation of a greatly increasing number of sewage treatment biological processes to offset the effects from many types of common trade wastes which from the chemical standpoint present problems parallel with the metallic and gas poisons used in warfare. It is prudent, moreover, in these days of national defense, to bend all useful peacetime developments toward protection from all reasonably possible wartime exigencies.

There is need to know:

(1) What wartime poisons used either in projectiles, bombs, solution or dust, and spread either by accident, bombardment or sabotage might affect either water or sewage?

(2) What poisons because of cost, weight, insolubility, low toxicity, hydrolysis to innocuous products, or non-availability of supply are eliminated from practical consideration?

(3) In what manner might poisons gain access to water or sewage?

(4) What are the effects on human beings, sewage treatment plants, agricultural crops, fish, plankton and bacterial life in streams, and the potability of water supplies taken from below sewage discharges containing poisons either in their active form or from their hydrolysis products?

(5) How can present tests be used or modified to detect warfare poisons in sewage?

(6) What revisions should be made in "Standard Methods of Water Analysis" to cover the subject of metallic and war gas poisons in water and sewage?

It will be impossible in this paper to outline any suggested general schedule of metallic and war gas poison tests because for the most part the tests now being experimented with for water analysis have not been adapted for sewage work.

An attempt will be made to touch on some of the practical aspects involved and to outline a few suggestions with the hope that other contributors will develop the subject as it applies to local requirements.

A critical survey indicates only a relatively few of the war poison materials are involved in water or sewage. These materials may be roughly grouped as follows:

1. Arsenical compounds.
2. Heavy metals.
3. Cyanides, cresols and phenols.
4. Glucosides and alkaloids.
5. War gases proper.

Arsenical compounds include such inorganic substances as arsenic insect sprays and organic arsine compounds typical of the newer war gases which are far more dangerous. Such compounds are readily soluble in water and are generally stated to be toxic in amounts greater than 0.15 p.p.m. Arsenical compounds are not removed in sewage treatment plants and, therefore, threaten water supplies which are sewage laden. Sewage treatment plant operators should be aware that erythema might be caused by handling sewage with parts of the body possessing open sores or cuts when the arsenic organically bound reaches a concentration of 40-50 p.p.m. In some instances death might ensue. Inorganic arsenical compounds possess no such power. Arsenic, with diabolical intent, has been added to the newer types of war gases such as "lewisite" and "ethyl dichlorarsine" so that after the gas itself has created open wounds and bleeding, death follows from the absorption of the arsenic content in the same gas. Such gases are known as "blistering" gases and some even after hydrolysis in water still possess blistering characteristics.

Inorganic heavy metal poisons include lead nitrate, lead acetate, mercuric cyanide, mercury nitrate, mercury sulphocyanate, barium hydroxide, barium iodide, barium oxide, barium nitrate, copper sulphate, zinc cyanide, zinc chloride, zinc sulphate and others. Lead salts are heavy and react with chlorides, carbonates and sulphates in the water causing milkiness with consequent loss in toxicity. Lead is an accumulative poison and does not taste at its generally accepted toxic concentration of 0.1 p.p.m. It would probably not be selected as a poisoning agent in moderately mineralized waters or sewages, particularly where sulphates or chlorides are high. Mercury salts, while expensive, are readily available and in forms which do not react with ions in the water or sewage such that the poisoning influence can be carried through treatment plants and into streams which might affect subsequent water supplies. Barium compounds are readily available from paint plants, some industrial water softening plants, and various industries. In some cases these barium salts are insoluble in water but may readily be converted into soluble compounds. Barium compounds after reacting with the water might easily permit soluble barium to be run through a treatment plant with ease. High sulphate waters would lessen such a danger. Copper and zinc salts react so rapidly with the alkalinity of water or sewage that heroic doses would have to be used and trouble ordinarily need not be anticipated. Zinc salts are used for disinfection at gymnasiums and camps in the control of fungus diseases and are readily available in large quantities. Zinc cyanide is troublesome on account of its cyanide content. There is not much likelihood of the salts of antimony, bismuth, or tin being added to water in sufficient quantities to cause trouble.

The heavy metals in organic combination are exceedingly toxic due to the

inability of the body fluids to neutralize and eliminate them. They are polar compounds which do not ionize; therefore they do not react and the body cannot precipitate them nor would they tend to precipitate in aqueous solution. Their solubility is usually low in water, but they are infinitely more toxic than the same element in inorganic combination. Hence it is important to differentiate between metals in organic and inorganic solution. Gasoline containing tetra ethyl lead could easily be added to either water or sewage and be spread widely before the gasoline lost its identity and organically bound lead could be widely dispersed.

The group of cyanides, cresols, and phenols from trade wastes are receiving increasing recognition in stream pollution. Cyanides are generally stated to be toxic at 30-60 p.p.m. They react with water to form harmless compounds but danger may be caused from materials continuously liberating hydrocyanic acid. Cresols and phenols in the absence of free chlorine produce a taste as low as 0.1 to 0.3 p.p.m., while heavy doses might upset a sewage treatment plant and if not removed by proper treatment may cause tastes and odors in subsequent water supplies.

The glucosides and alkaloids cover a large group of materials many of which are used in industrial plant processes and some of which are natural by-products, all of which in many cases are already reaching sewers. Glucosides are saponins which sud easily and are obtained from the hydrolysis of organic esters from vegetable products. When combined with chromium and other heavy metals they are used for slime control solely for industrial purposes and are extremely poisonous. The common commercial sodium glucosides used in rust prevention in domestic hot water piping systems are harmless. The cyanogenic glucosides and the digitalis group of saponins are toxic to man at 10 p.p.m. or less and others, such as picrotoxin and stropanthin may be toxic to fish at lower concentrations.

The most troublesome alkaloid poisons in this connection are nicotine and strychnine, although there are others more deadly. Nicotine sulphate is commonly known as "Black Leaf 40" in the control of pests. Strychnine is not as dangerous because it is less soluble and less toxic but is easily obtainable. All alkaloids give a bitter taste to water but may be toxic at concentrations too low to taste. Of the hundreds of alkaloids, the majority are soluble only as acid salts and when added to an alkaline water immediately precipitate but in sewage their solubility is increased. A few alkaloids remain in solution on the alkaline side of both water and sewage. Colchicine and nicotine are freely soluble in alkaline water and their toxicity is less than 1 p.p.m. Aconitine, capsaicin, and physostigmine are toxic at 10 p.p.m. or less. It is thus apparent that 1 lb. of nicotine sulphate used for gardening purposes put either into water or sewage could produce alarming results. Likewise, it is apparent that other alkaloids should be given attention.

Of the fifty to sixty war gases developed at the end of the last war, the three main groups of interest here are (1) the arsines, derivatives of which are toxic in water solutions; (2) mustard gas; and (3) gases liberating hydrocyanic gas. The arsenical gases include adamsite, lewisite, methyldichlorarsine, ethyldichlorarsine, phenyldichlorarsine, diphenylchlorarsine, diphenylaminecyanarsine. Some of these gases, including the second to fourth mentioned above, are vesicant after hydrolysis. The toxicity based on arsenic is about 0.15 p.p.m. Mustard gas is toxic at about 40-50 p.p.m. but is soon hydrolyzed and is there-

fore harmless so far as complications in water supplies and sewerage works is concerned.

From the practical standpoint, toxic doses of any of the above mentioned poisons could easily reach reservoirs or sewers. A single large airplane or a fleet of small planes could place ten tons of material in a reservoir in a single attack. If the reservoir is of ten million gallons capacity, then such a dose would give a concentration of 24 p.p.m. which is above the toxic limits of most of the poisons above mentioned. A reservoir so polluted might have to be emptied at once. The discharge of a reservoir so polluted into a sewer system would readily admit excessive poisonous doses into the sewer system. The deliberate addition of chemicals into the water distribution system through house services or into the sewer system through house connections is possible. In the former case, ingenious devices might be necessary but in the latter, toilet bowls present an open opportunity.

Certain materials if dumped in a reservoir would require long periods to mix or to hydrolyze and their pernicious effects might slowly increase.

Generally stated, there is apparently an opportunity for a wide group of poisons in toxic quantities to reach sewer systems and the havoc which might be created is alarming even though dilution progresses as the sewage flows to the treatment works. It is also true that residual effects of some poisons which react with the sewage might still persist through the treatment works in toxic quantities. Some of the possible consequences include:

1. Maintenance operators in sewers and sewage pumping plants may be subject to gassing with fatal results from gases not detectable by odor.
2. Operators not careful in handling sewage and who have open body sores or cuts may be poisoned.
3. Operators should notice any abnormal increase or decrease in sewage odors in sewers.
4. Sludge digestion in separate sludge digestion may be stopped and it may not be possible to secure a readily drying sludge.
5. Activated sludge may be bulked or even destroyed.
6. Sprinkling filters and bio filters may be completely denuded of slime.
7. The final effluent may contain poisons which if the water is used for irrigation may destroy crops or if discharged into streams may still, in spite of dilution, be toxic to algae, plankton, and fish.
8. Sewage containing poisons is always a threat to water supplies when such sewage is discharged into streams used for domestic purposes.

It therefore appears that the serious danger of poison pollution of water and sewage is not a figment of the imagination but is a stark reality.

TESTS ON POISONS

So far, the literature on tests for poisons has been limited to field army tests. Much literature on war gases, so far as universal application is concerned, is in error because of subsequent changes in gas manufacture, difference in impurities and variance in the conditions of testing. In this new field the ordinary tests used in water and sewage treatment plants do not cover the needs of the laboratory technician. There is need first, to understand correlations in variations of present analyses with war gas poison pollution; second, to develop qualitative tests for the detection of arsenic, mercury, and cyanide; and third, to give serious consideration to a future program for a more complete schedule of tests to cover the entire field.

1. *INTERPRETATION OF PRESENT TESTS*

The operator should always be on his guard to notice variations in the common tests and not to regard abnormal variations as "flukes."

(a) *Chlorides*

The chloride determinations at sewage treatment plants vary considerably reflecting various amounts of ground water, peak sewage flow, and the discharge of industrial wastes. However, in sewages normally high in chlorides which suddenly show an abnormally low chloride content, there might have been the addition of silver, mercury, or lead. The operator should, therefore, be on the watch for an unusual variation even in this simple chloride test. Abnormally high chlorides might indicate the hydrolysis of war gases, most of which contain chlorine.

(b) *Sulphates*

If sulphates are normally present in the sewage, a low determination might be due to the addition of lead or barium salts. An increase in sulphates may be caused by the addition of copper or zinc sulphate. A few gases have sulphates as hydrolysis products, hence an increase in sulphates may be due to some war gases.

(c) *Oxygen Consumed*

Although the oxygen consumed value varies in raw sewage, any large increase may be due to war gases, glucosides, alkaloids, or phenols. This test is an immediate indication of danger and where the oxygen consumed is greater than what normally might be expectd, as a normal correlation between oxygen consumed and physical appearance of the sample, suspicion of the operator should be aroused and additional tests made.

(d) *Biochemical Oxygen Demand*

Any sudden increase in biochemical oxygen demand above normal expectancy would be due to organic substances in rather minor amounts and of hydrolyzed war gas products. It is easy to see how the biochemical oxygen demand might be abnormally low in the presence of metallic poisons, glucosides, and alkaloids, and war gases if present in toxic amounts. These materials would have to be destroyed or removed before authentic biochemical oxygen demand results could be obtained, just as in the case of determining biochemical oxygen demand in the presence of free chlorine.

(e) *pH*

Most war gases hydrolyze in water and produce acid which lowers both the alkalinity and pH. In distilled water the pH may be reduced to 2.0. In reasonably good drinking water a pH of 4.0 is not unreasonable. The depression of pH in sewage because of increased buffering action would not be so marked, yet it might be measurable. Barium hydroxide in excess would cause an increased pH.

(f) *Grease*

War gases are usually dissolved in wood alcohol, acetone, or benzene, and such materials if discharged into sewers would pick up grease and cause erratic grease results in treatment plants.

(g) *Nitrates*

Since many of the heavy metallic poisons are soluble and available in the nitrate form, those plants running the nitrate determination should be on the lookout for abnormal variations.

(h) *Odor*

While not too much stress should be paid to odor because gases can be

cleverly masked to conceal odor, nevertheless most gases have a characteristic odor which can never be forgotten. When once an operator has noticed a certain odor he should identify it as near as possible to its cause so that this experience can be utilized for future comparisons.

2. *INTRODUCTION OF NEW PROCEDURES*

Tentatively, a few rough tests should be instituted in addition to present determinations including chlorine demand, a modified oxygen consumed test, and a qualitative test for metals including arsenic.

(a) *Chlorine Demand*

It is recommended that the chlorine demand test be made on all sewage and sewage effluents regularly. Since most war gases will react readily with several equivalents of free chlorine, it is evident that the chlorine demand test modified on this basis is able to pick up minor quantities having significant value.

(b) *Oxygen Consumed Test Modified*

Small quantities of war gases produce high oxygen consumed values and are immediately oxidized. It is suggested that the digestion period be reduced to five minutes.

(c) *Heavy metals and arsenic by hydrogen sulphide precipitation.*

Such a test might include: first, evaporating to fumes 500 ml. of sewage in sulphuric and nitric acid until the solution is practically colorless; and second, the dilution of the residue with water and finally precipitation of the heavy metals with hydrogen sulphide. If heavy metals are present, there will be variously colored precipitates. A whitish precipitate of sulphur may obscure the yellowish precipitate of arsenic in quantities roughly below 10 p.p.m., but in larger concentrations arsenic is readily noticed.

(d) *Arsenic in quantities less than 10 p.p.m.*

The best tentative arsenic test including inorganic arsenic and organic arsenicals is good to 1 ppm. Concentration may be used for lesser amounts. To 100 ml. of sample is added 5 ml. of concentrated sulphuric acid and sufficient concentrated nitric and hydrogen peroxide to decolorize. The sample is headed to SO_3 fumes in a Kjeldahl flask. The residue is dissolved in distilled water and reduced with 0.1 gm. of hydrazine sulphate followed by boiling till sulfur dioxide has been completely removed. After cooling, 30 ml. of water, 5 ml. conc. HCL, and 0.2 gm. potassium bromide are added followed by titration with 0.01N $KBrO_3$ using methyl orange indicator. The titration is to the disappearance of the pink color.

This test is a good qualitative procedure and fairly good quantitatively, but positive results in all cases should be checked with the longer Gutzeit or Marsh procedures.

(e) *Spectrograph*

The spectrograph is the quickest and easiest method to determine the presence of abnormal amounts of all heavy metallic poisons in extremely small amounts. It is also useful in the detection of arsenic but is not sensitive below 1 p.p.m. Spectrographs are now available in forensic laboratories in leading police departments, at leading universities, and in a few progressive sanitary laboratories. Such equipment should be used where convenient.

While it is recommended that the present laboratory tests made by the operator should be watched for the variations above indicated and be correlated to possible additions of metallic and war gas poisons, the writer is of the firm opinion that the other tests above mentioned should be adapted for immediate use. This is recommended not only as a preparedness measure but because of the additional value of such information being readily adapted to practical use so far as the disposal of trade wastes into sewers is concerned.

SEWERAGE FACILITIES IN ARMY CANTONMENTS IN MONTEREY COUNTY

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The comments in this paper will be confined to the area of Monterey County, because we are not familiar with the work that has been done elsewhere. Situated in Monterey County are seven and possibly eight areas which are either directly or indirectly connected with army projects. So far as sewage disposal is concerned, there is in addition a federal public works building project with a separate sewage disposal plant. The area at the Presidio of Monterey and in the East Garrison of Fort Ord had more or less established sewage facilities before the present defense program was started. The Presidio of Monterey disposes of its sewage by screening and discharging into Monterey Bay along with the sewage from the City of Monterey. Some time ago the East Garrison of Fort Ord had erected a Doten tank with leaching beds and frequently used a by-pass to the Salinas River last year. For summer maneuvers, when the camp was well filled, pit privies were also used. In the process of construction is another Doten tank and 6 more leaching beds. The beds in use at present seem to be more nearly adequate since the heavy rains appear to have stopped, and since a large number of men have moved from East Garrison to West Garrison. The by-pass is now reported to be sealed. With the defense activities greatly expanded and more land purchased along the Monterey Bay waterfront it was found that a large camp was to be established in West Garrison or Camp Clayton. The local health department with the Bureau of Sanitary Engineering took the matter up with the USPHS for consultation with the army authorities who were to construct the sewerage facilities for this area. Because the Monterey Beach is used for recreational purposes, largely fishing and picknicking as well as a certain amount of clam digging toward the northern end of this area, we felt that it was very essential that this beach be protected against sewage contamination. A request was made for a treatment plant to be installed, without specifying the type of treatment plant which should be placed there. Unfortunately, there are treatment plants and treatment plants. During the time the present treatment plant was under construction, raw sewage was by-passed to the ocean with an outlet some distance beyond the beach. Because of shifting sand and storms, this pipe soon broke and raw feces were discharged on the beach and could be found for a ½ to ¾ mile up the beach toward Santa Cruz and perhaps somewhat less than that distance

South of the outlet. The treatment plant has consisted of a moderate size septic tank, the operation of which you are familiar. The odors are quite noticeable on the highway. When an experienced operator takes over this plant it is hoped that this can be eliminated. The effluent from this plant at present has no visible solid materials in it and is not noticeably contaminating the beach. The beach is supposed to be a "closed area." What will happen in the future is difficult to see. The effect on clams outside the military area may not be known for some time either. This septic tank also has a by-pass in case it becomes overloaded. Another sewage disposal plant will be installed on the Fort Ord reservation by the Federal Public Works Project which is building 264 homes on the South side of Fort Ord for non-commissioned officers' families. The type of treatment plant will probably be that of trickling filter or leaching beds in the sand dunes, either of which would give fairly high grade treatment with no contamination of the beach.

At the southern end of the county is our next largest camp, Camp Roberts, which should accommodate around 21,000 men eventually. We are concerned with the disposal of sewage into the Salinas River because it is used by residents during the Summer time for bathing. One of our two resident cases of typhoid during 1940 had been bathing in this river within 2 to 4 weeks before he became ill and died with the disease. The Salinas River in this hot, dry southern part of Monterey County affords an opportunity for swimming. It was therefore essential that a high grade treatment plant be placed in Camp Roberts. The army authorities therefore constructed a very good trickling filter sewage disposal plant with chlorination and aeration before discharge into the river. As far as we have been able to ascertain, the Bradley branch of Camp Roberts will discharge its sewage into this treatment plant also. What sewerage facilities will be provided for the homes of enlisted men's families is unknown at present.

Camp Hunter Liggett at Jolon is primarily a maneuvering area of 156,000 acres. Except for the officers' quarters, there will probably be very few if any permanent buildings or any permanent sewage disposal system. Pit privies are expected to be used as if the men were actually in the field and on the march.

Although they are perhaps less publicized, there are three army training fields for army air pilots located in Monterey County; one at King City, one at Monterey and the other at Salinas. The Salinas airport which consists of some 300-400 acres is located near the reclamation ditch which drains a part of the Salinas Valley. Barracks and other facilities have been built to house perhaps 200-300 men. A large septic tank was dug through this heavy clay soil and provided with a number of leaching lines to take care of the effluent. The plant was well constructed and under normal circumstances should have cared for the effluent, but with a large area of the field to be under concrete runways and the heavy rainfall this Winter, it seems possible that this sewage disposal system may not be adequate. At present it seems that some arrangement is made for the drainage ditch to take this surface water and perhaps some of the effluent if the septic tank gets too full and the numerous leaching lines cannot take it.

The Monterey airport, where no men will be kept in barracks as far as is known now, will be used only as a flying field. There the sewage disposal is by means of a concrete septic tank 4x12 feet with an unknown depth,

with approximately 300 feet of leaching line. This septic tank is large enough to take care of the three public toilets which they have. The leaching line which was installed within the last 6 months was laid by the City of Monterey. The sewerage system appears to be satisfactory except that drains from the cement floors in the hangars emit odors indicating possibly that they were improperly trapped.

At the King City Airport, another 200-300 men are expected to be in training for air pilots. A good many of their buildings are built and already in use. A Los Angeles Company contracted to install the sewerage system there which consists of cesspools with grease traps ahead of them, followed by more cesspools to take up whatever effluent was not absorbed by the first ones. These holes in the ground are approximately 4 ft. in diameter and approximately 10-15 ft. deep where they went through an 8-10 ft. layer of rather absorptive sand. How adequate this arrangement will be and how many additional holes will have to be dug, of course, will not be known until the plant has been in use for some time. As far as is known, this is not a water bearing sand, inasmuch as there are no wells near that have water which is satisfactory for drinking purposes.

Other camps may be built in the southern part of Monterey County, but as yet the plans are too nebulous to know anything about their location, much less their sewerage facilities.

In general, one might summarize by stating that with the exception of the Fort Ord area, the health and sanitation of the civilians of Monterey County has been well protected in the establishment of sewerage facilities in these army cantonments. Undoubtedly this Fort Ord problem will be corrected soon. We feel that although the army was quite willing and anxious to cooperate in most cases, this might not have been true had it not been for the unstinting and persevering work of the State Bureau of Sanitary Engineering. Their engineers have given this county a great deal of time and effort and were always willing to assist us and to be ever on the alert for the improvement of sewerage facilities. The Monterey County Health Department does not have a sanitary engineer on its staff and must depend upon the State Department of Public Health for this activity, which service has been granted to us most generously. It is hoped that in the near future if the Fort Ord sewerage facilities prove themselves inadequate that funds will be appropriated by the army authorities for better treatment of the sewage emanating from these two sources. With the by-pass at East Garrison to the Salinas River completely sealed, the sewage should be adequately handled on the reservation; and if it is felt that the septic tanks at West Garrison can adequately care for the large number of men which are expected to be brought into this area, perhaps the present treatment plant will be adequate.

APPLICATION OF PRESENT SEWER LEGISLATION

By **HOMER W. BUCKLEY**
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Mr. Chairman and Gentlemen of the Association, your Secretary has requested me to speak upon the subject of "Application of Present Sewer Legislation." By "present" legislation I take it that means the various legislative enactments that apply to cities. There are a number of legislative acts that apply to counties exclusively and several that provide for the creation of sanitary districts which may or may not include cities as well as unincorporated territory. I shall undertake to discuss only those legislative enactments that apply primarily to cities and which provide for proceedings to be initiated by the city council.

A review of these acts is quite appropriate at this time for the reason that most of the law relating to sewers and sewage disposal was repealed by the 1939 Legislature and codified in the new Health and Safety Code. In several instances overlapping and duplicating statutes have been eliminated entirely or clarified. So it is well to re-examine the present statutory law relating to sewers in order to reorient ourselves in relation to the present law and the new codification.

I shall confine myself to a brief outline of the principal provisions of the law and shall give you a reference to where the statute may be found so that you, or your legal counsel, may examine the statute itself for more specific details.

The legislative enactments roughly divide themselves into four groups. These groups are:

1. Those providing for acquirement of rights of way within and without a city.
2. Those providing for raising money with which to construct a sewer system.
3. Those providing for cooperative and joint action between cities, counties and cities, or districts and cities.
4. Those providing for the construction and operation of a sewer system upon a self-liquidating revenue bond basis.

In the first group we find Deering's Act 5192. That Act provides:

> "Any municipal corporation or sanitary district, under such terms and conditions as may be prescribed by the legislative body thereof, is hereby authorized and empowered to permit any other municipal corporation or santary district to construct and maintain sewers . . . in, across or along the streets or other public places of such municipal corporation or sanitary district . . ."

The Act then provides a procedure for the granting of such permit, the principal provision being that it is based upon mutual agreement. The act is flexible and permits two governmental bodies to work out the problem of rights of way through an adjoining area in such manner as may best fit their own needs.

A similar act is Deering's Act 5193, which provides:

> "There is hereby granted to every municipal corporation . . . The right to construct, operate and maintain . . . sewers . . . across, along, in, under, over, or upon any road, street, alley . . . or highway . . ."

within any city or "within any other municipal corporation . . ." Thus any two cities may enter into an agreement specifying the terms and conditions

by which one city may acquire the right of way for a sewer through the other.

The interesting provision of this Act is that part which provides a procedure whereby one city can request the Superior Court of the county to "determine and adjudicate the terms and conditions" under which it may use the streets of another city if the two municipalities cannot agree upon those terms. So if your city desires to construct a sewer and of necessity must have a right of way through the corporate limits of another city and the two municipalities cannot agree upon the terms and conditions under which the right of way is to be granted the city desiring the right of way may file an action in the Superior Court of the county requesting the court to determine what is a fair and equitable agreement between them. The Act provides that upon the court's final judgment in the action the city desiring to use the streets of another city may enter upon the work under the terms and conditions and at the locations specified in such judgment.

Section 117 of the Streets and Highways Code is applicable to state highways within cities. Under the provisions of this section the Department of Public Works is empowered to permit the location of sewers, pipes and drains within the right of way of state highways. Whenever the State of California takes over a street within your city and makes it a state highway the jurisdiction over that street passes to the state, and it is necessary for the city to obtain permission from the Department of Public Works to do any work within the right of way of that state highway. Therefore, if your city desires to lay a sewer, or any other drainage system, within the right of way of a state highway within your city a special permit must be obtained from the Department of Public Works.

The "Sewer Right of Way Act of 1921" was repealed by the 1939 Legislature and codified in the Health and Safety Code in Section 7558 seq. This Act as codified in the Health and Safety Code provides a procedure for the acquirement of property, easements and rights of way for sewers and drains for sanitation and drainage purposes.

The Council is authorized to pass an ordinance of intention describing the proposed improvement and the district that will be benefited and which is to be assessed to pay for the improvement. If the owners of a majority of the frontage of property within the proposed district protest the proceedings must be dropped. If the Council orders the proceeding to be carried through it has the power then to proceed to purchase the necessary property, easements and rights of way, or to acquire them by condemnation. The sections then set up a procedure for the levy of assessments to pay the cost of such acquirements.

These provisions of the Code provide, as you will note, only a procedure for the acquirement of such property, easements and rights of way as may be necessary for a sewer or drainage system and provides for the payment of such expenses by assessment upon the property to be benefited. The Act does not make any provision for the construction, operation or maintenance of any system.

The second group of acts relate to the raising of revenue for the construction of a sewer system.

The Act previously known as the "Municipal Sewer District Act of 1911" is now codified in Section 4600 seq. of the Health and Safety Code.

This codification provides that a city Council may create within a city

separate districts "to construct or acquire sewers," and provides a procedure for incurring a bonded indebtedness to pay for such sewer construction.

The Code provides that a city Council may, after public hearing on an ordinance of public interest and convenience, call an election and submit to the people a proposition for the voting of bonds to carry out such construction.

A two-thirds vote is required to authorize the issuance of bonds and the bonds when issued become general obligations of the city, and the Council is required to annually levy upon all property within the district a tax sufficient to pay the principal and interest of the bonds, which must be retired in an amount of not less than 1/40th each year.

There are two general acts that provide a procedure for the issuance of general obligation bonds for all types of public improvements which, of course, includes construction of sewers. These statutes are Deering's Acts 5178 and 6424. These two acts are the principal ones used in the voting of General Obligation Bonds and must be kept in mind when considering methods of raising revenue for any public improvement. It requires a two-thirds vote for their issuance and they must be retired within a period of forty (40) years, and the principal and interest must be paid annually by revenue raised by general levy upon all property within the city. The procedure provided for in Section 4600 of the Health and Safety Code has the advantage that the principal and interest of the bonds must be met by taxes levied within the district benefited, while these two general bond acts are retired from taxes levied on all property within the city.

The third group of statutes pertain to acts that authorize cooperative and joint action between cities, between counties and cities and between cities and sanitary districts.

Before discussing those acts that deal expressly with sewer matters it might be of interest to you if I commented briefly upon a recent agreement executed between the Cities of Berkeley, Alameda, Piedmont, Emeryville, Richmond and Albany.

By that agreement the City of Berkeley contracted with the other six cities to conduct an extensive investigation as to the best and most economical method of sewage disposal for the seven cities involved.

The agreement was drafted under the terms of Deering's Act of 1801. That Act is couched in general language and should be of interest to every sewage engineer because it opens up a field of cooperation between cties, counties and cities for the solution of mutual problems by cooperative agreements. The Act is very short and the most important language reads:

"Two or more counties, two or more municipalities, or one or more municipalities and one or more counties by agreement entered into respectively by them, and authorized by their legislative bodies, may jointly exercise any power or powers common to the several contracting parties.

"Such agreements shall state the purpose of the agreement or the power to be exercised and provided for the method by which the purpose sought shall be accomplished or the manner in which the power shall be exercised.

"The parties to such agreement may provide that the contributions from the treasuries may be made for the purpose for which the agreement was entered into or payments of public funds shall be made to defray the costs thereof which funds may be made to and disbursed by such agencies as may be agreed upon . . ."

Under the language of this statute the agreement between Berkeley, Oakland and the other cities provided that the City of Berkeley would conduct the survey but that in the conduct of such survey it would not employ

any persons or enter into any contracts or disburse any money that did not meet the approval of an Executive Committee that was provided for in the agreement. The Executive Committee was composed of an official representative of each of the cities to the contract. In other words, while Berkeley carried out the survey all work done by it was to be done under the jurisdiction, supervision and direction of a committee representing all of the contracting cities.

The language of the Act that I have just quoted and the contract as construed by the Supreme Court in the case of *In re Controversy between the City of Oakland and Harry G. Williams, as Auditor,* found in 99 Cal. Dec. 445. In that case the court held that the contract was legal and stated that under the provisions of Act 1801, cities and counties could enter into agreements with each other for the performance of any act which they both had the power to perform separately.

If your city and the adjacent unincorporated territory, or another city, have a problem that requires cooperative action for its solution this Act provides a very excellent procedure of cooperative section in its solution.

Section 4660 seq. of the Health and Safety Code codifies an act frequently referred to as the "Sewer District Act of 1899." This Act is valuable in solving some of the troublesome problems of congested areas and unincorporated territory adjacent to a city.

Under these sections of the Health and Safety the Board of Supervisors upon petition of one-third of the voters of any unincorporated district may by a two-thirds vote create a sanitary district. The Board of Supervisors thereafter has the power to construct and maintain a sewage system within the district so created.

The interesting and important portion of the Act, so far as cities are concerned, is that the Board of Supervisors is empowered to contract with adjacent cities for the connection of the sewer system of the district with the adjacent city's sewer system. Such connection is empowered to be made upon such terms and conditions and for such compensation as the Board of Supervisors and the City Council may agree, and the agreement so made may be changed from time to time by mutual agreement.

The Board of Supervisors is empowered to levy taxes upon all property within the district to pay for the cost of construction and maintenance of the system and for the connection with the adjacent city's system.

Deering's Act 5192, which I have previously mentioned provides that:

". . . two or more municipal corporations, two or more sanitary districts, or one or more municipal corporations, and one or more sanitary districts . . . may enter into a joint agreement . . . for the joint construction and maintenance of sewers . . . in . . . either or any of such municipal corporations or sanitary districts, including the joint construction and maintenance of all necessary outfall sewers . . ."

This Act also provides that two or more cities or sanitary districts may:

". . . enter into an agreement . . . with each other for the joint use of . . . any sewers, outfalls . . . constructed in whole or in part in the streets or other public places of either . . . upon such terms and conditions as they by mutual agreement may, by their respective . . . legislative bodies, determine to be proper."

This Act thus provides two things, first, that several cities may enter into a joint agreement for the construction and maintenance of a sewer system; secondly, for the joint use of any system previously constructed.

The fourth group of acts provides for the issuance of revenue bonds, and

for self-supporting operation by the area benefited. This type of legislation has been slow in coming to this state. The charters of several large cities of this state have authorized the issuance of revenue bonds but most of the charter cities and all sixth class cities have had to rely upon the state law for a procedure to issue revenue bonds and this power has been denied in sewer matters until quite recently.

The first act that provided a procedure for the issuance of revenue bonds was enacted by the 1933 Legislature, and is usually referred to as "Sewer Revenue Bond Act."

I spoke before this section at the Santa Barbara Convention several years ago on the subject of "Sewer Rentals," and made reference to this Act. I pointed out that the Act seemed to be limited in its application to the sole situation where the revenue bonds were sold to the "Reconstruction Finance Corporation or other fiscal agent of the United States."

In the interim between that Convention and the present one that Act has been amended and codified in the Health and Safety Code in Section 4957, seq. and the limitation just mentioned has been eliminated. The Act now provides that a city council may create a district which may include the whole city or a portion of the city, and issue revenue bonds for the acquisition of easements and rights of way, and for the construction of a sewer system within the district.

There are several things in this Act that are of the interest and justify your attention. First, under the Act the council itself may create the district and issue the bonds. Usually one or both of these acts are based upon election by the people. The Act requires the council to provide for a hearing, and provides that "if a majority of the owners of improved real property" file a protest the proceeding must be abandoned. Also a written petition signed by 15% of the owners of the improved real property may require the proposition to be submitted to an election but in the absence of such a petition all power is vested in the city council.

The petition protesting against the creation of the district and the election held pursuant thereto are of considerable interest because for the first time in this state, so far as I am aware, the ownership of property is a prerequisite to voting.

Under sections 4975 to 4977, inclusive, the ownership of improved real property is made the basis for the signing of the petition and is the qualification for the right to vote at an election that may be called pursuant to the filing of the petition.

The bonds required are to be of the serial type and must be discharged within forty years from the date of issue.

Another interesting provision is that the rates for the use of the sewer system is levied not on the owner of the property served but "upon the person leasing or occupying the building or premises served." The rate is levied by the council and may vary according to the different class of use, but the rate must be sufficient to raise enough revenue to pay principal and interest plus "cost of operation, repair, replacement and maintenance." This proviso may be enforced by any bondholder.

The next point of importance in this Act that requires examination is the method of collecting the money due for the use of the system from the person who is required to pay it. Two methods are provided. First, a civil action may be maintained against the person "who occupied the premises when the services were rendered." Second, the rate may be added to and collected with "any other utility service rendered by the city."

The method of collection seems to me to be weak because the amount of money involved does not on the average justify the expense involved in collecting the rate by legal action. The expense in preparing the action, filing it, serving process, trial and satisfaction of judgment in most instances would exceed the amount of money involved.

The 1939 Legislature adopted the "Sewer District Revenue Bond Act of 1939" (Deering's Act 7560). This Act is probably more flexible and more practicable in execution than the one just previously mentioned, but it has the limitation that it must be created by an election of the people in the area affected.

The proceeding for the creation of a district may be initiated by a verified petition signed by not less than 10% of the qualified electors. If the petition is sufficient, the council is required to adopt an ordinance of intention to call an election to submit the proposition of creating the district and the issuance of the bonds. After a public hearing the council may overrule the protests or may sustain the protests and abandon the proceedings.

The bonds if voted must be payable in amounts of not less than 1/40th each year but the whole amount must be repaid within twenty-five years from the date of issuance. The date of first maturity may be delayed for not more than three years from the date of issuance. Thus, you would have three years within which to construct the improvement and get into operation before the first bond maturity and interest would fall due.

The bonds are first lien on all revenue and no free service may be rendered to anyone, including the United States government, the state, county, city, school district, etc. Anyone using the service must pay the full price.

The provisions of the Act providing for the collection of the charges for the use of the system are very effective. First the charges are a lien upon the property served. This lien may be foreclosed by a civil action. Second, a civil action may be maintained against the person who occupied the premises when the service was rendered, and third, the City Treasurer may sell the property against which the charges are a lien if the rates have been delinquent for more than six months.

Another incentive to pay the rate promptly is that a 25% penalty is required to be imposed for failure to pay promptly.

The Act provides that all inhabited buildings within 100 feet of the system must be connected with the system. Charges must be made for connections with the system and such charges must be paid prior to making the connections.

All revenue derived from operating the system must be accounted for separately from all other city funds. Separate funds are provided for the retirement of the bonds, the payment of interest, operation and maintenance of the system and for a reserve.

This, gentlemen, is a brief reference to all of the present statutory legislation relating to sewers. What I have given you is but a brief outline of what I believe to be the principal points in each act. There is a great deal of information in each of these acts that I have not mentioned or even referred to. If you desire more information and greater detail than I have given you I refer you to the several acts themselves and to the sections of the Health and Safety Code, and more particularly to your City Attorney.

PORT ORFORD CEDAR AT TREATMENT PLANTS

By **EDGAR A. BROWN**

Special Representative Port Orford Cedar Association

At the outset let me say that this subject is approached in the complete realization that wood must have a minor and not a major place in any construction connected with sewage practice. These minor uses, however, could attach to themselves considerable importance, with the result that the selection of a good species to serve certain purposes would follow careful study of available materials.

Through the good offices of the United States Forest Products Laboratory, Madison, Wisconsin, information is today readily obtainable on the properties, qualities, and characteristics of every known commercial species of wood. The Laboratory's studies, though, are concentrated on the development of information related to the most generally known uses of woods. As a consequence, certain very practical uses of wood species receive little or no mention in the Government data and literature. As an xample of this, Port Orford Cedar has long been favored by engineers for heavy-traffic flooring, suc has in freight sheds, warehouses, ferry boat decks, and piers. Despite this preference, we find no mention of the wood's superiority in this sense, in Government literature.

It is well, at this point, to describe Port Orford Cedar. The tree is cone-bearing, of size and height comparable to the average Douglas Fir, and is native to the coast of northern California and southern Oregon. Colloquially it is sometimes called Lawson Cypress, or White Cedar, or Ginger Pine. Very recently, the Forest Service has renamed the species Port Orford White cedar. This was deemed advisable to differentiate the wood from Western Red cedar and Incense cedar. In this paper we will use the term Port Orford cedar.

Port Orford cedar is a surprising wood. Ordinarily the wood possessing great decay and rot resistance is compensatingly low in strength qualities. The fact that Port Orford had unexampled durability coupled with splendid general strength, early drew it to the attention of engineers and builders. A word comparison helps to make this obvious. Port Orford cedar, in the seasoned state, has the rupture value of Inland Empire fir; side compression equal to that of chestnut; end compression equivalent to hemlock; the shock resistance of Short Leaf yellow pine; shear value not exceeded by Sitka spruce; and the stiffness of Western larch. That, in a few words, goes to explain the liking which has been shown for Port Orford cedar.

It rested with chemical engineers to discover a property of Port Orford cedar which was to result in its greatest exploitation. The lead plate of electric storage batteries must be separated from one another by a material which has low electrical resistance and is able to withstand the destructive action of sulphuric acid. Port Orford cedar met these severe requirements admirably. To this day, no material has successfully challenged the supremacy of Port Orford cedar in the manufacture of storage battery separators.

The fact that Port Orford cedar is not injured by contact with acids, opened a field of uses which was officially recognized by the United States Bureau of Standards. This Bureau rates the wood highly in such uses as tanks, vats, pipe, etc. The explanation of this behavior of Port Orford cedar lies in one of its constituents, an oil of low volatility. This oil imparts to the wood its pleasant aroma, which unmistakably identifies the species. The oil accounts also, for the long life of Port Orford cedar under conditions which subject it to wetting and drying. Unlike woods which are durable up to the point of solubility of their extractives, Port Orford cedar is resistive indefinitely to the action of water.

Wood technology divides its subject into two general groups, viz: the hardwoods and the softwoods. Port Orford cedar is in the category of the softwoods. Curiously, however, it exhibits characteristics which have gained for it a reputation not held by other members of the softwood family. This is a reputation for long wear under traffic of any kind. A single familiar reference is the decks of the erstwhile ferry boats on San Francisco Bay. It seems safe to say that nowhere was there an intensity of traffic the equal of that to which their decks were subjected, nor such punishment from the elements. Those decks, every one of them, were Port Orford cedar.

In searching for an explanation of the wearing quality of Port Orford cedar, we are somewhat mystified. Possibly it results from the minute celular structure of the wood, or from the fact that the springwood part of the annual ring growth is not greatly different from that of the summer growth. Possibly the analogy of long-staple and short-staple cotton might be used—Port Orford cedar being compared to the long-staple, in that it does not readily give up its fibres. Instead of splintering, it shreds or fuzzes. An amusing incident in this connection was the decision of a Port Orford cedar mill to engage in the manufacture of pencils. The project was a rapid failure. Port Orford cedar, with its tenaciousness, refused to be subdued to the dull jaws of a pencil sharpener. It had too much wearing quality.

Now, how may these properties and qualities of Port Orford cedar be used by the designer and operator of a sewage plant or system?

Decay resistance and immunity to acid action would recommend it to the engineer's attention for such items as (1) Grillages in trickling filters, (2) Wood stave pipe for outfalls, (3) Lining for existing brick or concrete sewers which have been attacked by sewage residue and gases, (4) Foundation or trestle construction of any character, (5) Sludge pits, or (6) Any incidental work where lumber or timber is to be in cantact with soil or subjected to alternating conditions of wetness and dryness.

The exceptional strength of Port Orford Cedar, which gained it equality with Douglas fir in the construction of bridges in the Oregon highway system, opens possibilities for its use when funds place a limitation on concrete construction, but some form of alternative durable construction is desired.

The close conjunction of the units in a sewage treatment plant often results in concrete formwork being complicated in the extreme. It seems logical that lumber and timber of proven strength and durability could be employed to simplify this condition, and cut the cost considerably. In this suggestion the thought is that stairs, platforms, catwalks, roofs and roof framing, etc., are more or less complex and costly in concrete, and that high efficiency, as well as lost cost, could be assured through the use of wood construction with a material such as Port Orford cedar.

Warehouses, shops and other utility buildings form part of sewage plants or departmental structures. The prevailing practice has been to employ monolithic floors for these buildings because of the fact that they must stand up under the wear and tear of storage and handling of appliances and equipment. The ruggedness of Port Orford cedar, under any form of mechanical abuse, warrants the engineer giving careful consideration to its use for any flooring problem. A homely evidence of the worthiness of this wood for heavy duty flooring is the railroad baggage room| Port Orford cedar has long been a common standard with railroads for this service. Another demonstration is the familiar platforms from which refrigerator cars are iced in transit. No floor could be called upon to endure worse punishment. Here again, Port Orford cedar has no competitors.

Port Orford cedar lends itself well to the ingenuity of the designer or builder. From one particular use, he expands it to another. Not being limited in its application, through deficiencies in strength, the wood can be made to serve in many capacities. Illustrative of this is the experience of one of our large power companies. More than twenty years ago, it instituted the use of Port Orford cedar for mud sills on its power poles crossing the decay-hazardous peat lands of the San Joaquin Delta. The next use appears to have been flume boards in the Company's mountain divisions. Later, Port Orford cedar was adopted for the construction of walkways under the tideland transmission lines. Then, very recently, we find the same Company inaugurating the use of Port Orford cedar for the timbering of its water tunnels. This illustration is typical of many others. It should be mentioned that the production of this serviceable wood is not limited to small-dimension material. Large timber is being shipped continuously from the Port Orford cedar mills.

In closing this brief description of one of the notable timber species of the Pacific Coast and its uses, it is well to remark that lumber yards, generally, do not carry stocks of Port Orford cedar. This circumstance, however, has never deterred the engineer familiar with the wood, from specifying it for mill shipment, as in the case of creasoted or other preservative-treated lumber or timber.

We of the lumber persuasion find many articles and materials reaching for and capturing the markets which were once counted as ours. Economic design, however, assays the annual cost of one method or one material as against another. Consequently, it greatly behooves the manufacturer to make known the unusual merits, if any, of his product. To some of you, Port Orford cedar may have been just another kind of wood. If these brief specific comments have served to kindle your interest in its possibilities, the producers will feel very gratified.

NOTES

From the Secretary's File

New members to be welcomed into the Association include:

Bishop, Frank M.	Nasi, Kaarlo W.
Barbour, Paul L.	Nugent, Lee M.
Cobleigh, William	Page, Roland C.
Fong, Paul	Peirson, Henry C.
Harrison, John B.	Reidell, Alfred G.
Hustead, Clarence P.	Rudolf, R. L.
Larson, John A.	Spencer, Henry
Ludwig, Russell G.	Trotter, Roy M.
McKeen, William H.	Van Zandt, James O.
Medbury, H. Christopher	Vaughn, W. J.
Meeden, J.	Webb, Rollin D.
Montgomery, James M.	Wilkins, George F.

H. W. Schuck and Clinton Henning were reinstated.

It is noted with some regret that the following are in arrears in the payment of 1941 dues, and unless these dues are paid before the October Meeting, it will be necessary to apply for reinstatement:

Bates, John S.	Pickett, Arthur G.
Calif. Packing Corporation	Town of Pleasanton
Clements, Paul N.	Robles, George
Darnell, F. M.	Schapp, A.
Edwards, H. L.	Segel, A.
Fiscus, A. E.	Smith, Alva J.
Gregory, Ted R.	Studley, E. G.
Harmon, Judson A.	Swanson, S. C.
Henry, B. F.	Tegtmeyer, L. G.
Jewett, Herbert A.	Unger, Carl
Lefever, R. W.	Van Norman, J. H.
Mauldin, P. L.	Villaruz, Primo
Morrison, C. B.	Watkins, H. H.
Neville, Jabez E.	Webb, L. C.
Parkes, G. A.	West, Ezra
Peterson, J. F.	Wirt, J. Benton

Without question, the payment of these dues is an oversight on the part of many members.

The lady guests of the members attending the Santa Cruz Meeting, had an exceptionally fine time, according to all reports.

The trip to Big Basin and luncheon at Brookdale Lodge were highlights of the ladies' entertainment.

It is our understanding that Herb Foster is now in the service and is stationed at Camp Callan near San Diego. A. M. Rawn has been called as a consultant on Federal projects.

Occasionally, the Association has a chance to do a good turn for one of its foreign members. Gregorio De Leon, Chief Engineer of the Metropolitan Water District at Manila, P. I., is a visitor in the United States, and the Association has attempted to place him in contact with the many people throughout the country whom he wishes to see.

President C. A. Emerson, at the Meeting in Santa Cruz, urged operators to let their ingenuity at the home plant be known to other people. Responding to this plea, Wayland Jones, Frank Faccini, and Thomas Gwin have prepared sketches of certain gadgets used in their plants which are being forwarded to W. H. Wisely, Executive Secretary of the Federation. These items will be used from time to time to enhance the value of the SEWAGE WORKS JOURNAL to the operator.

Jack Kimball is now Sanitary Engineer of the Orange County Health Department, Santa Ana. Harold May has taken Jack's place as Assistant Superintendent of the Division of Water & Sewers at Palo Alto.

A good many of the members of the California Sewage Works Association were able to attend the sessions of the Arizona Water & Sewage Works Association Meeting in Yuma, Arizona, March 13, 1941. Among those participating in the program were: W. J. O'Connell, A. M. Rawn and R. F. Goudey.

Frank De Martini has been appointed to the position of Past Assistant Sanitary Engineer of the United States Public Health Service with headquarters at Washington.

In Memoriam

With a feeling of shock and a sense of extreme loss, this Association regretfully announces the passing of one of the younger members.

A. CARL BEYER was killed in an automobile accident, April 30, a week and a day after many of us had participated with him in many activities of the Spring Conference.

Mr. Beyer was born in St. Paul, Minnesota in 1901. He graduated from the University of California in 1925, and ranked as a top student in Sanitary Engineering. Prior to his association with the Wallace & Tiernan Company in 1929, he held positions with the City of San Rafael and the Pelton Water Wheel Company of California. Mr. Beyer had recently been advanced to the position of manager of the San Francisco office of Wallace & Tiernan Company.

Mr. Beyer was an associate member of the American Society of Civil Engineers, and quite active in San Francisco Section affairs. He was a member of the American Water Works Association and chairman of the Purification Division of the California Section. He had just completed two years of valuable service as a member of the Board of Control of the Federation of Sewage Works Associations, as a representative of the California Sewage Works Association. He had been a member of the Association since 1929.

Carl's presence and valuable opinion will be missed by this Association for years to come.

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